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PHILIPPINE COALS AS FUEL.

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INTRODUCTION.

While it may be true that the testing of fuels under boilers gives only approximately comparative results, nevertheless are is degree of accuracy in assumptions such as that of Bazin,[1] who conside the practical steam-making capacity of a combustible mateal to two-thirds of its found heating value. This capacity may var from per cent with the best anthracite down to 50 per cent or evenless whe a highly bituminous coal is used. The type of plant, the personn and other important factors must be considered. The error in concludin that a coal high in evaporative power is on that account the best coa and conversely that a very cheap fuel necessarily must be cheap in the long run should be guarded against. The most satisfactory way in which a correct conclusion as to the respective commercial values of different coals can be arrived at is to make tests and then comp are their performances as shown below.

There is no doubt that steam vessels can successfully use sor ne of the Philippine coals. If others are too high in volatile combustibl e matter they unquestionably can be employed by mixing them with a certain amount of Australian coal and thus too rapid gasification be pr evented. The Coast Guard and interisland ships now burn on the average 10 ton of Australian coal each per day or 300 tons per month. If they replace

[1] *Rev. gen. de Chim.* (1904), 7, 91; Rev. in *J. Am. Chem* 27, 1333.

75024.

all or two-thirds by Philippine coal it would require only a simple calculation from the following data when the prices per ton are known. to determine the difference in cost.

I know of but one trial of the commercial value of Philippine coal where complete data of the test were kept. This was made about two years ago at the Philippine Cold Storage and Ice Plant.[2] The test was as satisfactory as possible under the existing conditions; the results exceeded the anticipations of those in charge of the test and seemed to indicate "its equality with many other coals on the Manila market." However, the grates were not adapted to the fuel and much inconvenience was experienced because the decrepitated coal passed through the grate with the ash. Toward the end of the test, this ash was burned over again and after the second burning the analyses of this Bureau showed it to contain 62.6 per cent of combustible matter. No comparative tests were made with other coals.

In 1904 the United States Army transports *Chukong*, *Sacramento* and *Palawan* made runs on Batan coal and the reports in each case were rable. The coal was easily fired, it burned well, the amount of soot comparatively small, there was no great quantity of smoke, the nt o. ash was low and there was no clinker.

e object of the following investigation was to determine the steaming value of the coals of the Philippine Islands, as measured by t of water evaporated per kilo of fuel when used under a boiler, as npared with the foreign coals offered on the market in this Archipelago; has also been my purpose to make a comparative study of the individual oals as well as to convert into useful work the greatest possible percentage of heat units contained in each. Careful and complete records have been preserved of each test; therefore it should be possible for engineers to determine from the data which are given whether or not the conditions were those best suited to the coal under examination and when a price is established for these coals, these tables will form a basis of comparison not only as to the water evaporated per kilo of fuel, but also in regard to the water evaporated per peso of fuel cost. In commercial operations the all important question is to find the fuel which will run a plant with the least financial outlay.

A spe grate was tried for some of the coals and an effort has been made to use a method of firing which would give the best results. As the supply of material at my disposal was limited, except in the case of Australian coal, only a small amount of preliminary experimenting could be done to determine the best practice in regard to firing and to gain information regarding the fuel before beginning the test. An engineer always needs experience with a coal to burn it in the most manner. It will be noticed from the tables that in some cases

[2] *The Far Eastern Review*, January (1908).

the efficiency for the second run is slightly higher than that for the first, showing the benefit of the first day's experience; however, in no case is the difference much greater than the possible error from other sources. Several preliminary trials were made on the coal regularly used here for firing in order thoroughly to test the working condition of the apparatus. It would have been very desirable to have had duplicate determinations of the steaming quality of each coal, but this was not always possible with the supply on hand; nevertheless it is believed that all the results are complete and sufficiently reliable to show the nature and indicate the real fuel value of the coal; in fact it has recently been shown [3] that more than one test of a coal is superfluous. Seventy-seven first tests gave an average efficiency of 66.05 and seventy-seven second tests an average of 66.02 and thirty-two third tests one of 65.87.

It is evident that promiscuous tests made under different conditions are not at all comparable, for it would be impossible to discover whether the variation was due to the fuel, the apparatus or the manipulation. However, in the work done at this Bureau many factors have been eliminated by using the same plant [4] and the same personnel; the others have been carefully controlled by using the same apparatus and maintaining all manipulations and general conditions as nearly uniformly constant as possible, except where a change in the second test was to the advantage of the coal. With the variable factors eliminated, the coals can be directly compared.

DESCRIPTION OF APPARATUS AND METHODS EMPLOYED.

All instruments used were carefully standardized and every precaution taken to prevent the possibility of error. As the nature of the coals to be burned was so entirely different, two sets of grates were provided.

The one was of plain, single bars 1.5 centimeters in width and constructed to give an air space of 1.2 centimeters between each pair, or a ratio between air space and grate surface of 20 to 45. The other, constructed for these tests and used with some of the coals, was a perforated grate with round, tapering holes 1.25 centimeters in diameter at the top, the smallest dimension, averaging 25 per square decimeter and giving a ratio between air space and grate surface of 18 to 45.

The two boilers shown in Plate I are exactly alike, the following description applies to both; however, with one exception, the tests were made with the one on the right; they can afford only a clue as to the efficiency of the boilers. This was not sought, for there are no means of comparing the boilers with others fired with Philippine coal, or perhaps with themselves under different conditions. The boiler was thoroughly

[3] Breckenridge, L. P., *U. S. G. S. Bull.* (1907), **325**, 32.

[4] The losses through radiation and conduction do not vary greatly for any given installation.

cleaned before beginning the test; it was in all cases used on the previous day so that the brickwork was thoroughly heated, and it was under full steam for some time on the day of the test before beginning the actual run. The gauge glass of each boiler was graduated into millimeters and calibrated independently with water at 30° C. These data were used to correct the water level between starting and stopping rather than by use of the pump.

BOILER:

Kind, Babcock and Wilcox.

Nominal rating, 75 horsepower.

Type, water tube.

Tubes:

Number, 45.

Diameter {external, 10.16 centimeters. internal, 9.48 centimeters.

Length exposed, 42.67 decimeters.

Drum:

Diameter, external, 9.15 decimeters.

Length, external, 58.4 decimeters.

	Square decimeters.
Water-heating surface—	
Of tubes	5,715.2
Of drum	718.8
Total	6,434.0

Steam gauge, Ashcroft's, graduated to 5 pounds on a 12-inch dial.

FURNACE:

Kind, Hand fired.

Height {front, 12.2 decimeters. back, 8.3 decimeters.

Width, 9.90 decimeters.

Flue connecting to chimney:

Length, 18.3 decimeters.

Calorimeter, 49.4 square decimeters.

Grate:

Kind, gridiron bar or perforated as best adapted to the individual coal.

Width, 9.90 decimeters.

Length, 18.3 decimeters.

Area, 181.2 square decimeters.

Ratio of water heating surface to grate surface, 35.7 : 1.

CHIMNEY:

Diameter, internal, 12.2 decimeters (4 English feet).

Height above grate, 30.5 meters (100 English feet).

Area, 38.33 square decimeters.

The stack was high enough in all cases to give the draft necessary for the coal in the condition used.

Draft, natural.

We have no economizer.

The exhaust main passes through a 200-horsepower Wainwright even-flow feed-water heater.

During all of these tests the steam was used to operate a large duplex steam pump, to drive the engine which furnishes the power to operate the air compressor, the vacuum pump, the refrigerating machine and many small motors, etc., for the laboratory and to supply live steam throughout the building. At first I intended to take switch-board readings, but the idea was given up as impracticable. Owing to the intermittent use of steam for other purposes such readings would necessarily be incomplete; but in Plates II to VII, I have given photographs of the volt meter and ammeter indicator diagrams. An estimation from these shows that an average of about 60 per cent of the steam produced was used by the engine, and 40 per cent for other purposes, including that condensed by radiation from the pipes. The equivalent evaporation per indicated horsepower was assumed as 25 kilos of water, because of the light and variable load of the engine.

The portable drop-lever Howe scales used in making the weighings were carefully standardized and found to be correct; the meter was fitted with a gauge and regulators so that it was calibrated from time to time by actually weighing the water passing through under the same head as it was fed into the boiler and no error was at any time detected in the registrations of the meter. If there was a slight error, being constant, it would affect alike all the tests and therefore be negligible in securing data for comparative purposes. The boiler feed pump was run intermittently and always at the same rate. The temperature of the water entering the boiler from the heater was determined by readings of a thermometer placed in a thermometer cup on the pipe just adjacent to the boiler. The steam gauges were tested by comparing with the test gauge of the Crosby Steam Gauge and Valve Company, a standard instrument manufactured by Schäffer & Budenberg, Limited, and that used by the city boiler inspector. The only errors were in the initial setting of the needles. These in all cases were corrected at a pressure of 20 pounds per square inch by actual trial with a column of mercury. The damper was controlled by a lever passing over a graduated segment.

The chemical thermometers were of 550° C. capacity, and were calibrated by the *Physikalisch-Technische Reichsanstalt* in Charlottenburg, Germany. The temperatures of the flue gases were read from a high-grade mercury thermometer which was calibrated from these. The usual U tube, or inverted siphon of water, draft-gauge was used. One arm was open to the atmosphere and the other, by means of the proper connections was inserted into the draft to be tested. The difficulties of reading the gauge were reduced to a minimum by the looking-glass scale. The latter was accurately divided into millimeters so that the error of reading was not greater than a few units in the decimal. The scale was movable, which greatly facilitated the reading of it.

A Barrus' continuous, surface condenser calorimeter was on hand during several of the tests to determine the moisture in the steam. Steam nearly always carries water with it and thus the boiler is credited with having evaporated more water than is really the case. However, the results recorded in Table II have not been corrected for this since I was unable to determine the factor for all. It will be seen from the following table that the boiler of this Bureau produces steam which is very uniform in quality and as the results

of the tests are intended to be comparable only, it is permissible to omit this constant correction entirely. It was not convenient to attach the calorimeter close to the boiler. It was attached to the steam pipe 22 feet away and owing to the radiation from this pipe, even though all parts were well covered, the amount of moisture may be somewhat high.

The readings were made on several days during the firing of coal from three different sources and at different times of day, so that the greatest variations of load are represented. These readings are shown in *Table I*.

TABLE I.—*Steam calorimeter readings.*

Date, 1907.	Time after starting.	Steam-gauge pressure.	Readings of thermometer.	
			Upper.	Lower.
	h. m.	*Kilos per sq. cm.*	°C.	°C.
June 19	5 20	7.8011	168	109
	5 45	7.8011	169	110
	6 10	7.8014	169	110
	6 35	7.1716	165	110
June 20	1 12	7.8011	167	109
	1 50	7.5232	167	109
	2 12	6.8260	161	110
	3 00	7.8011	168	110
	4 00	7.8011	168	110
	4 40	7.8011	167	109
	4 55	6.4685	161	108
	6 25	7.3925	166	111
June 21	2 40	7.5232	167	110
	3 20	7.1716	165.5	109.5
	5 50	7.5232	167.5	108.5
	6 20	7.5232	167	108.5
	6 30	7.1716	166	109
	6 45	7.8747	169	109
July 15	5 30	7.1716	163	110
	5 50	7.1716	163	110
July 16	1 30	7.1716	161	110
	1 50	7.4529	165	109
	4 40	7.3925	165	110
	5 05	7.1013	163	109
	5 20	7.8717	167	110.5
	6 15	7.5935	166	110

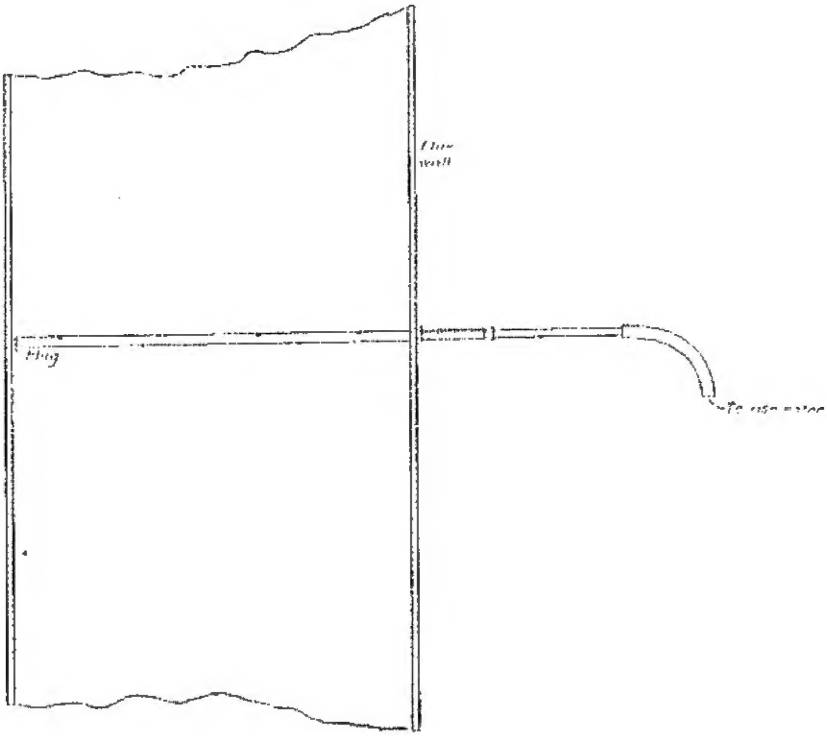


FIG. 1.

The apparatus consisted of an iron gas pipe of 1.5 centimeters internal diameter, passing through a suitable fixture attached to the shell of the chimney, long enough to extend across the flue and leave a few centimeters projecting. The inner end was capped and four holes 1.5 millimeters in diameter were bored, one 7.5 centimeters from each wall of the flue and the other two dividing the intervening distance into thirds. The two end holes were slightly enlarged (about 0.2 millimeter) to counter balance the increased draft in the middle of the chimney and the increased suction in the middle of the sampler when the gases were exhausted. A piece of glass tube was fitted into the open end of the iron pipe, by means of a tightly fitting plug, so that the end would reach to the middle of the perforated pipe. The apparatus was tested and proved to have tight joints. The sampler was inserted into the flue and the gases drawn off through the glass tube.[7] The holes were placed away from the current to prevent their being filled with soot. An aspirator was constructed of a large bottle fitted with the necessary siphon tubes.

A concentrated salt solution was used in the aspirator. It is realized that since the gases are somewhat soluble, this is not as accurate as their collection over mercury, but is probably as accurate as the sample itself.

[7] Attention has been called to the fact that samples taken with an apparatus similar to this compared very favorably with those taken with the sampler recommended by the American Society of Mechanical Engineers. *U. S. G. S., P. P.* 48 (1906), 2, 311.

The solubility of carbon dioxide, the most soluble of the chimney gases, is shown by the following data:

Carbon dioxide was bubbled for twenty-four hours through water and a salt solution under identical conditions, at 28° C. and atmospheric pressure. For each part of water, 0.649 volume of gas was dissolved, while the volume for each part of the salt solution was only 21 per cent of this amount. There can be little doubt that these are the saturation values, for that obtained for water agrees remarkably well with the results of other investigators. Calculated from the interpolation formula of Naccari and Pagliani,[8] $a=1.5062-0.036511t+0.0002917t^2$, the value for water is 0.647.

The chimney gases were never bubbled through the salt solution and were in contact with the surface for a short time only, so that any error must be slight. The same salt solution was used throughout the experiments and after several months intermittent use and exposure to the air contained less than 2 per cent of the saturation value for pure water.

The exposed end of the glass tubing of the sampler was attached to the aspirator, the siphon started and the gases gradually drawn off. Between the aspirator and the sampler a Fresenius tower filled with cotton was imposed to remove the soot. By means of pinchcocks the removal of the flue gases was maintained at a constant rate. The aspirator was removed at will and a new one put in its place. This operation was continued for any number of successive hours. The various samples of gas thus obtained were analyzed and reported as the average for that period. The analyses were made according to standard chemical methods. The absorption medium for oxygen was an alkaline pyrogallol solution.[9]

The unconsumed constituents of the flue gases—viz. carbonic oxide, hydrocarbons and soot—may at times be great and represent a considerable percentage of the calorific value of a coal. However, the only combustible gas determined was carbon monoxide (CO). When this gas is found in any quantity it is quite probable that hydrogen and hydrocarbon gases are also present, but because of the difficulty of determining these in small amounts their percentages have not been ascertained.

Chemical analyses.—Nitrogen in the coal was determined by the regular Kjeldahl method and all other analyses were made according to standard chemical methods.

Determination of the calorific value of the coal.—In the calculation of the calorific value of the coal from the ultimate analysis, Dulong's formula in the form as given in 1899 in the report of the Committee on Coal Analysis,[10] appointed by the American Chemical Society, was used as follows:

$$\text{Calorific power}=8{,}080C+34{,}400(H-\tfrac{1}{8}O)+2{,}250S.$$

[8] *Gazzetta chim. ital.* (1880), 10, 119; *Atti d. R. Ac. d. sc.*, Torino (1879–80), 15, 279.

[9] It has been maintained (Franzen, H. *Ztschr. f. anorg. Ch.* (1908), 57, 359.) since this work was done that this is not a satisfactory absorbent for analyzing gases where oxygen is present in large quantities, for the oxygen acts on the pyrogallol solution producing carbon monoxide (CO) which remains in the gas-rest and changes its composition. Alkaline sodium acid sulphite is recommended.

[10] *J. Am. Chem. Soc.* (1899), 21, 1130.

The determination of the calorific value of the coal was made in a Berthelot-Mahler bomb calorimeter under a pressure of 20 atmospheres of oxygen. The constants used were those which had been carefully determined for previous work and the corrections for wire fused, niter, sulphur, etc., were made according to the usual methods.

Color of the smoke.—In judging the color of the smoke the standard Ringelmann scheme was followed. The smoke was observed against a clear sky and its color compared with the effect upon the eye of a 20-centimeter square, black-and-white grating held at 15 to 20 meters distance. Plate VIII is a photograph of the standard charts used. No. 1 is the pure white paper, and No. 6 in the series is entirely black; hence each intermediate proportion corresponds to a 20 per cent range. Plate IX shows a small section of the upper left-hand corner of each grating drawn to the exact scale.

Method of firing.—It was found that all of these coals, except where there was a large amount of clinker, worked best when fired in small quantities every four or five minutes with spreading stoking.

Method of starting and stopping.—The alternate method was used, that is, the boiler was thoroughly heated by a preliminary run of an hour or more; during the last twenty minutes or half an hour of this time the fire was fed with the coal to be tested, then allowed to burn low, cleaned, left level and the amount of live coal left on the grate estimated. At the same time the pressure of steam, the water in the boiler and other observations were taken, and the time recorded as the starting time. Fresh coal which had been previously weighed was now fired and the ash pit cleaned immediately. Before the end of the trial the fire was allowed to burn low, just as before the start, again cleaned and left in the same condition and with the same amount of coal on the grate as at the beginning of the test. This stage was recorded as the stopping time.

The temperature of the fire room was not recorded, because in the tropics fire rooms are so constructed that when in use they are entirely open and are practically the same as if the stationary boiler had merely a roof over it. The fire room temperature may be taken as that of the air.

The ash represents that actually removed. It was not practicable to recover the ash carried over the bridge and into the flues.

The individual tests give the other conditions governing the trials. I have been guided in reporting the data and the results of these evaporation tests by the form advised by the Boiler Test Committee of the American Society of Mechanical Engineers,[11] and have made these as complete as possible to enable anyone to make whatever other calculations he may desire.

TESTS.

The following tables give the complete data obtained during and calculated from the various tests on coals made in this Bureau:

[11] Code of 1899, Kent's Mechanical Engineers' Pocket-Book, New York (1903), 690; *Univ. of Ill. Bull.* (1906), **3**, 21; International Library of Technology **7**, 36; etc.

TABLE II.—*Steaming tests of Philippine coals and others offered for sale on the Manila market.*

[The black-faced figures over columns are code numbers of the American Society of Mechanical Engineers.]

No. of test.	Source of coal.	Commercial size of coal.	Date of trial.	Kind of grate used.	Duration of trial. **2**	Average mercury barometer reading. Millimeters.	Average mercury barometer reading. Inches.	Average steam pressure by gauge—Per square centimeter.	Average steam pressure by gauge—Per square inch. **11**	Average steam pressure absolute[a]—Per square centimeter.	Average steam pressure absolute[a]—Per square inch.
					Hours.			*Kilos.*	*Pounds.*	*Kilos.*	*Pounds.*
	Australia:										
1	Westwaldsend[b]	Lump and slack	June 20, 1907	Perforated	7	757.76	29.83	7.416	105.5	8.450	120.2
2	Do.[c]	do	June 21, 1907	Gridiron	7	757.39	29.82	7.249	103.1	8.283	117.8
3	Do.[c]	Selected lump	June 5, 1908	do	7	756.94	29.80	7.797	110.9	8.831	125.6
4	Lichzow Valley	Lump and slack	May 6, 1908	do	6	757.36	29.82	7.906	112.5	8.940	127.2
5	Do.[d]	do	May 7, 1908	do	6¼	758.48	29.86	7.571	107.7	8.605	122.4
	Japan:										
6	Yoshinotani (Karatsu), Kiusiu Island	Lump	Apr. 22, 1908	do	7	758.03	29.84	7.831	111.4	8.865	126.1
7	Yubari (Hokkaido Province)	do	May 28, 1908	do	5	752.90	29.64	7.750	110.2	8.784	124.9
8	Borneo, Labuan	Pea to lump	July 15, 1907	do	7	756.94	29.80	6.834	97.2	7.868	111.9
9	do	do	July 16, 1907	do	6¾	755.15	29.73	7.265	101.7	8.399	119.4
	Batan Island:										
10	Military reservation[e]	Lump and slack	Jan. 14, 1908	do	7½	760.57	29.94	7.417	105.5	8.451	120.2
11	Do	do	Mar. 31, 1908	do	7⅓	759.47	29.90	7.761	110.4	8.795	125.1
12	Do	do	Apr. 2, 1908	do	7	759.42	29.90	7.761	110.4	8.795	125.1
13	Military reservation, seam No. 1	Lump	May 27, 1908	do	7	754.20	29.69	7.656	108.9	8.690	123.6
14	Do.[f]	do	June 2, 1908	do	6⅔	759.00	29.88	7.862	111.8	8.896	126.5
15	Betts'[g]	Lump and slack	Apr. 26, 1907	Perforated	4	758.85	29.88	4.471	63.6	5.505	78.3
16	Do	do	June 19, 1907	Gridiron	7	757.15	29.81	7.375	104.9	8.409	119.6
17	Cebu, Comansi	Lump	Nov. 14, 1907	do	5½	757.56	29.84	7.547	107.3	8.581	122.0
18	do	do	Nov. 12, 1907	do	7½	758.93	29.88	7.706	109.6	8.740	124.3
19	Polillo[h]	do	Dec. 21, 1905	do	24	760.79	29.95	10.898	155.	11.932	169.7
20	China, Hongay[i]		Dec. 4, 1906		24	759.88	29.92	10.898	155.	11.932	169.7

Footnotes follow at the end of the table, pp. 317, 318.

TABLE II.—*Steaming tests of Philippine coals and others offered for sale on the Manila market*—Continued.

[For source and commercial size of coal, date of trial, kind of grate used, and duration of trial, see p. 311.]

No. of test.	Average force of draft in millimeters of water.		Average temperature of—					Proximate analysis of the coal.[a]				Color of ash.	Specific gravity of the coal.
	Between damper and boiler.	In ash pit.	External air.	Steam, calculated.	Feed water entering heater.	Feed water entering boiler from heater.	Escaping flue gases.	Fixed carbon.	Volatile combustible matter.	Moisture.	Ash.		
	12	14	15	17	18	20	21	32	33	34	35		
			°C.	°C.	°C.	°C.	°C.						
1	12	-------	29.3	171.8	28	79.2	360	50.94	34.23	2.80	12.03	Pinkish gray	Variable, average 1.40.
2	11	-------	29.0	171.0	28	80.3	364	50.94	34.23	2.80	12.03	do	Do.
3	9	1	29.2	173.6	29	72.1	378	52.93	36.14	1.74	9.19	Gray	Do.
4	8	-------	31.0	174.2	30	72.1	391	52.62	32.47	2.11	12.80	do	
5	9	-------	30.8	172.6	30	71.3	409	52.62	32.47	2.11	12.80	do	
6	-------	-------	31.7	173.8	28	74.5	333	48.33	37.58	1.88	12.21	do	Variable, average 1.32.
7	-------	-------	27.0	173.1	29	70.0	395	42.69	45.60	1.32	10.39	Buff	Variable, average 1.27.
8	11	-------	31.0	168.8	28	76.5	377	50.55	41.35	5.43	2.67	Light red	1.29
9	11	1	25.5	171.5	28	76.8	398½	50.55	41.35	5.43	2.67	do	1.29
10	-------	-------	28.2	171.8	27	79.1	414	45.51	40.76	5.18	8.55	Reddish gray	Variable, average 1.30.
11	11	-------	31.2	173.5	29	78.9	310	49.41	38.36	5.88	6.45	Reddish brown	1.31
12	9	-------	30.5	173.5	29	78.9	334	50.20	35.59	8.87	4.84	do	1.30
13	9	-------	25.4	172.9	29	70.6	414	51.75	39.15	6.08	3.02	Reddish gray	1.31
14	9	-------	30.0	174.0	29	72.2	302	51.58	39.80	6.05	2.57	do	1.31
15	12½	1	30.7	154.7	29	77.9	406	38.33	36.56	18.03	7.08	Reddish brown	
16	12	-------	31.3	171.6	28	76.8	440	34.86	36.50	18.61	10.03	do	
17	9	-------	29.3	172.5	27	80.7	390	46.20	37.93	10.01	5.76	do	Average 1.32.
18	9	-------	30.0	173.2	27	81.8	312	46.27	37.95	9.94	5.84	do	Do.
19	21	-------	26.1	186.7	32	60.1	268	52.26	39.10	4.34	3.30	Brown	1.32
20	-------	-------	25.9	[b]262.2	29	58.3	[b]213	-------	-------	3.00	-------	-------	

Footnotes follow at the end of the table, pp. 317, 318.

TABLE II.—*Steaming tests of Philippine coals and others offered for sale on the Manila market*—Continued.

[For source and commercial size of coal, date of trial, kind of grate used, and duration of trial, see p. 311.]

No. of test.	Ultimate analysis of the coal. Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur. 36	Ash.	Calorific value, in calories, of the coal as fired, calculated from the ultimate analysis.	Calorific value, by oxygen calorimeter. Coal as fired.	Dry coal.[a] 30	Combustible.[a] 51	Coal as fired. Total 25	Per hour.	Dry coal[a] consumed. Total. 27	Per hour. 46	Per square decimeter of— Grate surface per hour. 18	Water heating surface per hour.
								Calories.	*Calories.*	*Calories.*	*Kilos.*	*Kilos.*	*Kilos.*	*Kilos.*	*Kilos.*	*Kilos.*
1	70.16	4.11	1.13	12.18	0.09	12.03	6,572	6,614	6,805	7,766	1,474.0	210.6	1,432.7	204.7	1.13	0.0317
2	70.16	4.11	1.13	12.18	0.09	12.03	6,572	6,611	6,805	7,766	1,497.0	213.9	1,455.1	207.9	1.14	0.0321
3	72.36	4.87	1.57	11.86	0.15	9.19	7,018	6,933	7,107	7,840	1,233.8	176.3	1,212.3	173.2	0.96	0.0268
4	-----	-----	-----	-----	0.58	12.80	-----	6,967	7,138	8,211	1,171.4	195.7	1,149.6	191.6	1.05	0.0296
5	-----	-----	-----	-----	0.58	12.90	-----	6,967	7,138	8,211	1,334.5	197.7	1,306.3	193.5	1.06	0.0299
6	67.20	5.15	1.02	13.41	0.91	12.31	6,674	6,691	6,516	7,793	1,634.0	233.4	1,604.1	229.1	1.26	0.0354
7	72.98	4.20	1.19	11.13	0.11	10.39	6,867	7,127	7,222	8,072	1,072.9	214.6	1,058.7	211.7	1.17	0.0327
8	68.55	5.45	1.11	21.48	0.74	2.67	6,507	6,664	7,047	7,251	1,791.0	255.9	1,693.7	242.0	1.34	0.0371
9	68.55	5.45	1.11	21.48	0.74	2.67	6,507	6,654	7,047	7,251	1,791.0	269.0	1,693.7	254.0	1.40	0.0393
10	65.00	5.41	0.96	19.98	0.10	8.55	6,253	6,079	6,411	7,316	1,917.8	259.7	1,846.9	246.2	1.26	0.0381
11	67.63	4.54	1.11	20.18	0.09	6.45	6,102	6,298	6,691	7,181	1,587.6	221.1	1,491.2	210.9	1.16	0.0326
12	68.78	4.62	1.15	20.51	0.09	4.84	6,269	6,359	6,755	7,125	1,502.6	223.2	1,470.9	210.1	1.16	0.0325
13	69.23	5.41	1.16	21.01	0.14	3.02	6,555	6,784	7,010	7,213	1,572.5	224.6	1,476.9	211.0	1.16	0.0326
14	69.45	5.43	1.17	21.09	0.19	2.57	6,554	6,640	7,035	7,238	1,404.3	205.5	1,319.3	193.4	1.07	0.0299
15	52.04	5.36	0.93	33.75	0.84	7.08	4,617	4,647	5,669	6,205	1,134.0	283.5	929.5	232.4	1.28	0.0359
16	51.06	5.29	0.91	31.53	1.21	10.03	4,018	4,560	5,602	6,390	2,313.1	230.7	1,882.9	200.0	1.18	0.0116
17	63.25	5.90	1.43	22.79	0.77	5.76	6,187	6,071	6,746	7,208	1,227.1	223.2	1,101.5	200.8	1.10	0.0309
18	63.34	5.59	1.43	22.67	0.83	4.84	6,192	6,009	6,720	7,206	1,246.0	208.8	1,110.3	188.1	1.04	0.0291
19	69.10	4.57	1.63	20.67	0.23	3.80	6,377	6,752	7,065	7,358	18,717.4	779.9	17,886.3	715.3	1.64	0.0401
20	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	19,755.6	-----	19,162.9	-----	-----	-----

Footnotes follow at the end of the table, pp. 317, 318.

TABLE II.—*Steaming tests of Philippine coals and others offered for sale on the Manila market*—Continued.

[For source and commercial size of coal, date of trial, kind of grate used, and rial, see p. 311.]

No. of test.	Equivalent evaporation of water from and at 100° C.								Efficiency of boiler including grate, in per cent, based on the chemical analysis.	Average humidity of air entering furnace, percentage of the saturated value for the temperature.	Rainfall during test, in millimeters.	Prevailing wind during test.		State of the weather.[j]
	Per hour.		Per kilo of—			Per kilo actually consumed[b]—								
	Kilos.	Per square decimeter of water-heating surface.	Coal as fired.	Dry coal.	Combustible.	Of coal as fired.	Of dry coal.	Of combustible.				Direction.	Force, in kilometers per hour.	
	63	64	69	70	71				72					
1	1,505.4	0.232	7.150	7.356	8.394	7.446	7.661	8.742	57.93	76.2	8.9	WSW.	21.7	o (gusty winds).
2	1,490.3	0.230	6.970	7.169	8.182	7.266	7.411	8.460	56.54	77.1	0.0	WSW.	18.8	o (gusty winds at intervals).
3	1,350.4	0.209	7.661	7.795	8.601	7.894	8.034	8.862	58.86	77.1	0.0	WSW.	12.0	o
4	1,310.3	0.203	6.691	6.839	7.867	7.003	7.154	8.230	51.40	65.6	9.0	ENE.	8.5	o
5	1,271.0	0.197	6.420	6.568	7.555	6.684	6.828	7.855	49.36	68.0	0.0	W.	10.1	c
6	1,150.7	0.178	4.930	5.022	5.741	5.157	5.253	6.005	39.53	51.2	0.0	W.	10.8	b
7	1,433.8	0.222	6.682	6.771	7.568	7.058	7.152	7.994	50.20	82.7	6.7	SSW.	31.8	o (squally).
8	1,390.6	0.215	5.435	5.747	5.914	5.661	5.986	6.160	43.75	69.3	0.0	WSW., SW	13.0	o, c
9	1,425.7	0.220	5.307	5.611	5.775	5.540	5.865	6.055	42.72	79.6	1.4	SW.	24.6	o (gusty winds at intervals).
10	1,207.7	0.187	4.650	4.904	5.390	5.148	5.431	5.969	41.04	70.2	0.0	NNW.	9.6	c
11	967.5	0.150	4.317	4.586	4.921	5.265	5.597	6.009	37.62	51.6	0.0	SE.	15.1	c
12	999.1	5.154	4.476	4.755	5.015	5.245	5.572	5.876	37.76	55.1	0.0	SE.	16.3	c (gusty winds at intervals p. m.).
13	1,437.7	0.222	6.400	6.815	7.041	7.225	7.693	7.948	52.15	92.2	28.1	SSE.	12.8	o, r (drizzle and rain at intervals).
14	1,373.3	0.213	6.692	7.113	7.313	7.370	7.845	8.065	54.21	75.2	0.0	SW.	13.2	o
15	1,254.7	0.194	4.926	5.100	5.910	4.748	5.786	6.333	51.10	59.8	0.0	W., WNW.	9.6	b
16	1,471.7	0.227	4.453	5.471	6.242	5.040	6.192	7.065	52.10	67.3	0.0	SW	18.9	c (thunderstorm).
17	1,335.8	0.207	5.985	6.651	7.106	6.089	6.766	7.230	52.89	64.3	0.0	WSW.	10.2	b
18	1,205.5	0.187	5.775	6.111	6.855	5.907	6.560	7.011	51.01	84.9	0.0	NNW., E	11.2	c
19	5,296.0	0.285	6.791	[f]7.106	[f]7.399	7.014	7.372	7.675	53.25	81.7	1.9	Variable.	5.4	c, o
20	4,775.0	....	[e]5.808	5.985	....	....	....	....	....	82.8	0.2	SW., ESE.	3.4	c

Footnotes follow at the end of the table, pp. 317, 318.

FOOTNOTES TO TABLE II, PP. 311–316.

[a] The barometric pressure was taken as uniformly equal to 1.033 kilograms per sq. cm. (14.7 lbs. per sq. in.) (30 inches in mercury).

[b] Mostly analyzed by Mr. H. S. Walker after the method of Cox. *This Journal Sec. A* (1907), 2, 41.

[c] Calculated from the proximate analysis.

[d] This does not include the ash carried over the bridge wall.

[e] Analyzed by Mr. M. Vivencio according to standard methods.

[f] The steam pressure and the temperature of the feed water must be considered. The total heat in calories from water at 0° C. of the saturated steam at 7.416 kilograms per square centimeter (105.5 lbs. per sq. in.) is 658.9 and that of the feed water is 28. These together with the kilos of water, 8,961.5, fed to the boiler, give the equivalent from and at 100° C. at atmospheric pressure as $\frac{658.9-28}{536.5}$ (factor of evaporation) $\times$ 8.961.5 = 10,538 kilos, 536.5 calories being taken as the latent heat of steam. For convenience these numbers are taken from Peabody's "Tables of the Properties of Saturated Steam," which are generally accepted by engineers. They may be calculated from the following formulæ on which the greater part of all tables is based:

$\lambda = 606.5 + 0.305t$ (v. Regnault, *Mém. de l'Acad.* (1847), **21**, 635.)

$\lambda = 589.5 - 0.7028t - 0.0031947t^2 + 0.0000084471t^3$ (Winkelmann, A., *Wied. Ann.* (1880), **9**, 208, 358.)

$r = 589.5 - 0.2972t - 0.0032147t^2 - 0.0000081471t^3$ (Winkelmann.)

where λ = the total heat of saturated steam through which the liquid at 0° is changed into steam at any temperature $t°$ and where r = the latent heat of saturated steam, through which the liquid at any temperature $t°$ is changed into steam at $t°$.

[g] 15.65 kilos of water evaporated per hour from and at 100° C. equals 1 horsepower.

[h] Calculated from the composition of the ash and the clinker, the calorific value of pure carbon and the fuel ratio and the calorific value of the coal.

[i] b = blue sky; c = cloudy sky; o = overcast sky; r = rain.

[j] This is the laboratory fuel furnished by the Bureau of Supply. It is "double-screened and picked twice." It was purchased on Circular Proposal No. 248 at a contract price delivered in Manila, piled in the coal sheds and yards of the Civil Government at ₱10.75 per ton of 2,240 pounds.

[k] The tendency of native firemen is to scatter coal high and in most of these tests there is undoubtedly needless smoke as well as some loss of heat energy. In this test exceptional effort was made to prevent the formation of smoke. In spite of the fact that this is lump coal which always produces less smoke the percentage still remains high, which indicates that it is impossible to burn this Australian coal with our setting without a considerable production of smoke.

[l] About 4 per cent of a soft incipient clinker which falls to pieces in dropping from the door of the furnace.

[m] This test shows the personal variation in firemen. A new man was put on. He could not keep his fire regular and the result was a somewhat low evaporation and at times high chimney temperature and low steam pressure.

[n] The clinker also contained 0.9 per cent of moisture and 5.1 per cent of volatile combustible matter showing that some coal was mechanically inclosed.

[o] This coal does not represent the vein for it had evidently lain in the tunnel where it had been water soaked and considerably silted over. The ash content and clinker-forming ability are therefore high as compared with the run of this coal. It was very difficult to obtain an accurate laboratory sample. The ash shown by the chemical analysis is considerably less than that of the coal actually fired.

[p] In the use of this fuel, the coal on the grate was not disturbed from start to finish. It was alternately semi-coked and spread-fired, and the result is more complete combustion, lower chimney temperature, and greater evaporation.

[q] Practically no smoke (under 10 per cent).

[r] This actually gives a negative value due to the oxidation of the iron.

[s] The test from which these data were calculated for purposes of comparison was made at the Insular Cold Storage and Ice Plant. *Far Eastern Review* (1906) 2, 223.

[t] 452.9 square decimeters of grate surface, 16½ per cent air space.

[u] 18.580 square decimeters of water heating surface.

[v] When the preceding numbers are compared with this they should probably be increased by a few per cent. Experience has shown that the larger the plant the less the loss due to radiation and that unaccounted for, and the water apparently evaporated is therefore larger by this amount.

[w] On December 4, 1906, the Manila Electric Railroad and Light Company made a 24-hour evaporative test on their boilers under regular operating condition with a mixture of Chinese and Australian coal using 19.756 and 30,402 kilos, respectively. The following day under as nearly identical conditions as possible a 24-hour evaporative test was made on Australian coal alone. They report that when using the mixture it was necessary to get assistance from one of the banked boilers when cleaning the fires and that during the peak of the evening load, straight Australian coal was used. Since the object of these tests was to determine the relative evaporative power of the two kinds of fuel, and since a poor coal owing to physical conditions often burns better when mixed with a better coal, it is at least fair to the Chinese coal to take the proportional part of the test on December 4, correcting for the amount of Australian coal used on the basis of the test of December 5. Data obtained by difference are never as satisfactory as direct data, but since I have not been able to make a test of Chinese coal and our information with regard to it is meager, it is thought that these data will give a fair idea of coal from this source and will represent in a general way the quality of the coal which may reach the Manila market from the China coast.

[x] 73°.5 superheating. The following calculations and results are based on the assumption of no superheating, for in the above tests this heat was lost through the stack. Recent investigation has shown that the specific heat of superheated steam is not constant, that it is approximately 0.65 for 55°.5 C. (100° F.) superheat and 0.75 for 111° C. (200° F.) superheat. Using these values, 9½ per cent of additional fuel was saved by the superheating to the degree named.

[y] The temperature was reduced to this value by the use of a superheater.

[z] The data of the Manila Electric Railroad and Light Company, show 8.00 for coal from Westwaldsend, Australia, which is 4 per cent higher than my selected sample and 10 per cent higher than my average sample of the same variety. In their test of Australian coal there was 82°.2 superheating. Using the values given in x, 11 per cent additional fuel was saved by this amount of superheating.

I am indebted to the Weather Bureau for the detailed data regarding the weather.

TABLE III.—*Heat balance or distribution of the heating value of the combustible.*

No. of test	1		2		3		4		5		6	
Source of the coal	Australia, Westwalsend.		Australia, Westwalsend.		Australia, Westwalsend.		Australia, Lichzow Valley.		Australia, Lichzow Valley.		Japan, Yoshinotani (Karatsu) Kiushu Island.	
Commercial size	Lump and slack.		Lump and slack.		Selected lump.		Lump and slack.		Lump and slack.		Lump.	
Factors.	Calories.	Per cent.	Calories.	Per cent.	Calories.	Per cent.	Calories.	Per cent.	Calories.	Per cent.	Calories.	Per cent.
1. Heat absorbed by the boiler[a]	4,504	57.99	4,390	56.53	4,615	58.86	4,221	51.40	4,053	49.36	3,080	39.53
2. Loss due to moisture in the coal[b]	24	0.31	24	0.31	15	0.19	19	0.23	19	0.23	15	0.19
3. Loss due to moisture formed by the burning of hydrogen[c]	171	2.20	171	2.20	162	2.04						
4. Loss due to heat carried away in dry chimney gases[d]											224	2.57
5. Loss due to incomplete combustion of carbon	1,300	16.75	1,344	17.32	2,079	26.55	1,290	15.70	1,285	15.65	1,027	13.18
6. Loss due to combustible in ash and refuse	253	3.26	45	.58	0	0.00	135	1.64	103	1.25	146	1.87
7. Loss due to unconsumed hydrogen and hydrocarbons, to heating the moisture in the air, to radiation and unaccounted for; some of these losses may be separately itemized if data are obtained from which they may be calculated	309	3.98	256	3.29	231	2.91	362	4.41	314	3.82	343	4.40
	1,205	15.51	1,536	19.77	738	9.42					2,958	37.96
Total		100.		100.		100.						100.
Total heat value of 1 unit of combustible	7,766		7,766		7,840		8,211		8,211		7,793	

Footnotes follow the table on pp. 321, 322.

TABLE III.—*Heat balance or distribution of the heating value of the combustible*—Continued.

No. of test	7		8		9		10		11		12		13	
Source of the coal	Japan, Yubari Hokkaido Province.		Borneo, Labuan.		Borneo, Labuan.		Batan Island, Military Reservation.		Batan Island, Military Reservation.		Batan Island, Military Reservation.		Batan Island, Military Reservation, seam No. 4.	
Commercial size	Lump.		Pea to lump		Pea to lump.		Lump and slack		Lump and slack		Lump and slack		Lump.	
Factors.	Calories.	Per cent	Calories.	Per cent.	Calories.	Per cent.	Calories.	Per cent	Calories.	Per cent.	Calories.	Per cent.	Calories.	Per cent.
1. Heat absorbed by the boiler [a]	4,060	50.30	3,173	43.75	3,098	42.72	2,892	41.04	2,701	37.62	2,690	37.76	3,777	52.15
2. Loss due to moisture in the coal [b]	12	0.15	21	0.29	22	0.30	46	0.65	47	0.65	47	0.66	51	0.70
3. Loss due to moisture formed by the burning of hydrogen [c]	189	2.34	183	2.52	186	2.56	197	2.79	129	1.79	133	1.87	191	2.63
4. Loss due to heat carried away in dry chimney gases [d]	1,342	16.63	1,346	18.42	1,216	16.80	1,202	17.07	1,276	17.75	1,720	24.15	1,444	19.95
5. Loss due to incomplete combustion of carbon [e]	158	1.96					0	0.00	362	5.04	520	7.36	222	3.06
6. Loss due to combustible in ash and refuse	430	5.33	289	3.99	313	4.32	684	9.70	1,299	18.06	1,045	14.66	828	11.42
7. Loss due to unconsumed hydrogen and hydrocarbons, to heating the moisture in the air, to radiation and unaccounted for; some of these losses may be separately itemized if data are obtained from which they may be calculated	1,881	23.29	2,248	31.03	2,416	33.30	2,025	28.75	1,370	19.09	964	13.52	730	10.09
Total		100.		100.		100.		100		100.		100.		100.
Total heat value of 1 unit of combustible	8,072		7,251		7,251		7,046		7,184		7,125		7,243	

Footnotes follow the table on pp. 321, 322.

No. of test	14		15		16		17		18		19		20	
Source of the coal	Batan Island, Military Reservation, seam No. 4.		Batan Island, Betts'.		Batan Island, Betts'.		Cebu, Comansi.		Cebu, Comansi.		Polillo.		China, Hongay.	
Commercial size	Lump.		Lump and slack		Lump and slack		Lump.		Lump.		Lump.			
Factors.	Calories.	Per cent.	Calories	Per cent.	Calories.	Per cent.	Calories.	Per cent.	Calories.	Per cent.	Calories.	Per cent.	Calories.	Per cent.
1. Heat absorbed by the boiler[a]	3,923	54.21	3,171	51.10	3,348	52.40	3,812	52.89	3,678	51.04	3,970	53.95		
2. Loss due to moisture in the coal[b]	49	0.68	181	2.92	200	3.13	88	1.22	85	1.18	34	0.46		
3. Loss due to moisture formed by the burning of hydrogen[c]	187	2.58	77	1.24	94	1.47	207	2.87	198	2.74	142	1.93		
4. Loss due to heat carried away in dry chimney gases[d]	1,661	22.97	914	14.72	1,012	15.83	1,308	18.05						
5. Loss due to incomplete combustion of carbon	27	0.37	66	1.06	68	1.06	513	7.11						
6. Loss due to combustible in ash and refuse	675	9.33	414	6.68	744	11.64	123	1.71	164	2.27	265	3.60		
7. Loss due to unconsumed hydrogen and hydrocarbons, to heating the moisture in the air, to radiation and unaccounted for; some of these losses may be separately itemized if data are obtained from which they may be calculated	711	9.83	1,382	22.28	924	14.47	1,162	16.12						
Total		100.		100.		100.		100.						
Total heat value of 1 unit of combustible	7,233		6,205		6,390		7,208		7,206		7,358			

[a] This value in calories = the water evaporated from and at 100°C × 536.5.

[b] This refers to the hygroscopic moisture only. The loss in calories = W $[100-t+536.5+0.48\ (T-100)]$ where W is the per cent of moisture referred to the combustible; t the fire-room temperature and T the temperature of the flue gases.

[c] This loss in calories = 9H $[100-t+536.5+0.48\ (T-100)]$ where H is the proportional part by weight of hydrogen in the dry coal.

[d] This loss in calories = the weight of the flue gases per unit weight of combustible × 0.24 $(T-t)$. This value is only approximate, as the sampling and the reading of the temperatures of the chimney gases are liable to considerable error. For this reason, as well as for the fact that there are many factors

that can not be determined, the heat balance itself is only approximate. When the ultimate analysis of a fuel is known, from a knowledge of the products of combustion, the air required with no excess for complete combustion is easily calculated. When there is more or less imperfect combustion and more or less excess of air entering a furnace the problem of calculating the weight of the flue-gases per kilo of combustible becomes more complex. A great many formulæ have been proposed to do this, but they seldom agree well, owing to the inaccuracies above mentioned. Kent, Steam boiler Economy (First Ed.), 32, shows that when the flue-gas analyisis is known the total amount of air supplied per unit of fuel is $3.032 \left\{\frac{N}{CO_2+CO}\right\} \times C$ where N, CO_2 and CO are the per cent by volume of nitrogen, carbon monoxide and carbon dioxide in the flue gases, and C the proportional part by weight of carbon in the fuel. The weight of flue gases will be *one* less the proportional part of ash in the fuel x, more than this, i.e., $3.032 \left\{\frac{N}{CO_2+CO}\right\} \times C+(1-x)$ where $(1-x)$ is the combustible and moisture in the fuel The Stirling Consolidated Boiler Co. (A Book on Steam for Engineers (1906), 183, New York) recommend as a check that the weight of air supplied per unit weight of fuel$=11.52\times\frac{CO_2+1/2\ CO+O}{CO_2+CO}\times C+34.56H$ where O is the per cent by volume of oxygen in the flue gases and H is the available hydrogen $(H-\frac{1}{8}O)$ in the fuel. The average of the results obtained by the use of these two formulæ has been used. In most cases the variation from this was less than 2 per cent.

[*] This loss in calories$=5{,}705\times\frac{CO}{CO+CO_2}\times C$ where the quantity 5,705 is the number of calories generated by burning one unit weight of carbon contained in carbon monoxide to carbon dioxide (calculated from the numbers of J. Thomsen, Thermo-chemische Untersuchungen (1882), 2, 52, 283 and 288) and as before CO and CO_2 are the per cent by volume in the flue gases, and C the proportional part by weight of carbon in the combustible.

TABLE IV.—*Observations in detail of the tests of coals from Australia, Japan, Borneo, and the Philippine Islands.*

A.—FIRST TEST OF COAL FROM WESTWALDSEND, AUSTRALIA—77 FIRINGS DURING 7-HOUR TEST.

[Test No. 1, Table II.]

Time after starting.	Steam pressure gauge.		Temperature of flue gases, base of stack.	Average composition of flue gases, in per cent			Kilos of coal burned—		Kilos of water fed to boiler—		Fire raked or sliced, time after starting.	Cleaned fire, time after starting.
	Kilos per square centimeter.	Pounds per square inch.		CO_2	O_2	CO	During period.	Total.	During period.	Total.		
											h. m.	*h. m.*
Beginning	7.172	102	360									0 00
¼ hour	7.312	101	340				60	60	325	325		
½ hour	7.453	106	355				60	120	325	650		
¾ hour	7.172	102	360				55	175	325	975		
1 hour	7.523	107	346				55	230	325	1,300		
1¼ hours	7.523	107	360				55	285	325	1,625		
1½ hours	7.523	107	357	9.0	8.0	1.62	55	340	325	1,950		
1¾ hours	7.382	105	351				55	395	325	2,275		
2 hours	7.664	109	343				50	445	325	2,600		
2¼ hours	7.453	106	363				50	495	325	2,925		
2½ hours	7.172	102	363				50	545	325	3,250	2 17	
2¾ hours	7.523	107	355				50	595	325	3,575		
3 hours	7.804	111	319				50	645	325	3,900		
3¼ hours	7.593	108	349				50	695	325	4,225	3 13	
3½ hours	7.312	104	355				50	745	325	4,550		
3¾ hours	7.523	107	355				50	795	325	4,875		
4 hours	7.734	110	340				50	845	325	5,200		
4¼ hours	7.382	105	338	10.0	7.5	0.0	50	895	325	5,525		
4½ hours	7.172	102	357				50	945	325	5,850		
4¾ hours	7.031	100	332				30	975	325	6,175		
5 hours	6.890	98	355				60	1,035	200	6,375		5 16
5¼ hours	7.453	106	357				60	1,095	300	6,675	5 01	
5½ hours	7.312	101	351				60	1,155	350	7,025		
5¾ hours	7.312	101	427				60	1,215	350	7,375		
6 hours	7.945	113	435				60	1,275	350	7,725		
6¼ hours	7.593	108	401	12.5	4.1	0.0	60	1,335	350	8,075		
6½ hours	7.804	111	371				60	1,395	350	8,425		
6¾ hours	7.523	107	355				60	1,455	350	8,775		
7 hours	6.820	97	------				19	1,474	186.5	8,961.5		7 00
Total	215.075	3,039	10,080	------	------	------	1,474	------	8,961.5	------	------	------
Average	7.416	105.5	360	------	------	------	52.6	------	316.4	------	------	------

TABLE IV.—*Observations in detail of the tests of coals*—Continued.

B.—SECOND TEST OF COAL FROM WESTWALDSEND, AUSTRALIA—84 FIRINGS DURING 7-HOUR TEST.

[Test No. 2, Table II.]

Time after starting.	Steam pressure gauge. Kilos per square centimeter.	Steam pressure gauge. Pounds per square inch	Temperature of flue gases, base of stack.	Average composition of flue gases, in per cent. CO_2	Average composition of flue gases, in per cent. O_2	Average composition of flue gases, in per cent. CO	Kilos of coal burned—During period.	Kilos of coal burned—Total.	Kilos of water fed to boiler—During period.	Kilos of water fed to boiler—Total.	Fire raked or sliced, time after starting.	Cleaned fire, time after starting.
											h. m.	*h. m.*
Beginning	6.961	99	360									0 00
¼ hour	7.031	100	400				60	60	325	325		
½ hour	7.453	106	355				60	120	325	650		
¾ hour	7.664	109	350				50	170	325	965	0 42	
1 hour	7.382	105	350				50	220	325	1,300		
1¼ hours	7.593	108	385	10.0	5.4	0.0	50	270	325	1,625		
1½ hours	7.664	109	355				50	320	325	1,950		
1¾ hours	7.593	108	350				50	370	325	2,275		
2 hours	7.523	107	335				50	420	325	2,600		
2¼ hours	7.172	102	350				50	470	325	2,925		
2½ hours	7.734	110	360				50	520	325	3,250		
2¾ hours	7.453	106	365				50	570	325	3,575		
3 hours	7.804	111	350				50	620	325	3,900		
3¼ hours	7.172	102	335				50	670	325	4,225		
3½ hours	7.172	102	340				50	720	325	4,550		
3¾ hours	7.664	109	340				50	770	325	4,875		
4 hours	7.875	112	340				50	820	325	5,200		
4¼ hours	7.172	102	380	10.2	6.3	0.0	60	880	300	5,500		4 15
4½ hours	6.961	99	360				60	940	200	5,700		
4¾ hours	6.539	93	350				60	1,000	250	5,950	4 31 4 35 4 39	
5 hours	5.976	85	360				60	1,060	250	6,200	4 53 4 57	
5¼ hours	5.625	80	390				60	1,120	250	6,450		
5½ hours	5.976	85	450				60	1,180	375	6,825		
5¾ hours	7.593	108	520				60	1,240	375	7,200		
6 hours	7.312	104	410				60	1,300	375	7,575		
6¼ hours	7.523	107	340	9.8	7.7	0.4	60	1,360	375	7,950		
6½ hours	7.172	102	330				60	1,420	375	8,325		
6¾ hours	7.875	112	330				60	1,480	375	8,700		
7 hours	7.593	108	320				17	1,497	175	8,875		7 00
Total	210 227	2,990	10,560				1,497		8,875			
Average	7.249	103.1	364				53½		317			

TABLE IV.—*Observations in detail of the tests of coals*—Continued.

C.—FIRST TEST OF LUMP COAL FROM WESTWALDSEND, AUSTRALIA—70 FIRINGS DURING 7-HOUR TEST.

[Test No. 3, Table II.]

Time after starting.	Steam pressure gauge. Kilos per square centimeter.	Steam pressure gauge. Pounds per square inch.	Temperature of flue gases, base of stack.	Average composition of flue gases, in per cent. CO_2	O_2	CO	Kilos of coal burned— During period.	Total.	Kilos of water fed to boiler— During period.	Total.	Fire raked or sliced, time after starting.	Cleaned fire, time after starting.
											h. m.	h. m.
Beginning	7.172	102	375									
¼ hour	7.312	104	383									0 00
½ hour	7.875	112	410				45	45	200	200		
¾ hour	8.156	116	400				45	90	250	450		
1 hour	8.086	115	381				45	135	250	700		
1¼ hours	8.015	114	384				45	180	300	1,000		
1½ hours	8.086	115	388				45	225	300	1,300		
1¾ hours	7.523	107	360	4.6	10.8	0.0	45	270	300	1,600		
2 hours	7.523	107	368				45	315	300	1,900		
2¼ hours	7.734	110	368				45	360	300	2,200		
2½ hours	8.437	120	388				45	405	300	2,500		
2¾ hours	7.875	112	355				45	450	300	2,800		
3 hours	7.891	111	364				45	495	300	3,100	2 12	
3¼ hours	7.242	103	365				45	540	300	3,400		
3½ hours	8.086	115	363				45	585	300	3,700		
3¾ hours	7.734	110	411				45	630	300	4,000		
4 hours	7.523	107	390				45	675	300	4,300		
4¼ hours	7.242	103	383				45	720	300	4,600		
4½ hours	7.891	111	370				45	765	300	4,900		
4¾ hours	7.523	107	392				45	810	300	5,200		
5 hours	7.664	109	367				45	855	300	5,500		
5¼ hours	8.226	117	396				45	900	300	5,800		4 51
5½ hours	7.523	107	368	9.1	8.6	0.0	45	945	300	6,100		
5¾ hours	8.015	114	276				45	990	300	6,400		
6 hours	7.664	109	396				45	1,035	300	6,700		
6¼ hours	8.086	115	370				45	1,080	300	7,000		
6½ hours	8.226	117	370				45	1,125	300	7,300		
6¾ hours	7.804	111	359				45	1,170	300	7,600		
7 hours	8.156	116	351				45	1,215	300	7,900		
							18.8	1,233.8	115	8,015		7 00
Total	226.116	3.216	10,971				1,233.8		8,045			
Average	7.797	110.9	378				44.1		287			

TABLE IV.—*Observations in detail of the tests of coals*—Continued.

D.—FIRST TEST OF COAL FROM LICHZOW VALLEY, AUSTRALIA—44 FIRINGS DURING 6-HOUR TEST.

[Test No. 4, Table II.]

Time after starting.	Steam pressure gauge. Kilos per square centimeter.	Steam pressure gauge. Pounds per square inch.	Temperature of flue gases, base of stack.	Average composition of flue gases, in per cent. CO_2	O_2	CO	Kilos of coal burned— During period.	Total.	Kilos of water fed to boiler— During period.	Total.	Fire raked or sliced, time after starting.	Cleaned fire, time after starting.
											h. m.	h. m.
Beginning	7.453	106	380									0 00
¼ hour	7.875	112	385				55	55	250	250		
½ hour	8.086	116	365				50	105	250	500		
¾ hour	7.593	108	375				50	155	250	750		
1 hour	7.734	110	385				50	205	300	1,050		
1¼ hours	7.734	110	355				50	255	300	1,350		
1½ hours	7.593	108	545	11.4	6.6	0.6	50	305	300	1,650	1 21	
1¾ hours	7.875	112	395				50	355	300	1,950		
2 hours	8.086	115	415				50	405	300	2,250		
2¼ hours	8.086	115	380				50	455	300	2,550		
2½ hours	7.593	108	350				50	505	300	2,850		
2¾ hours	8.226	117	393				50	555	300	3,150		
3 hours	7.734	110	423				50	605	300	3,450		
3¼ hours	7.804	111	392				40	645	300	3,750		3 09
3½ hours	8.297	118	400				55	700	300	4,050		
3¾ hours	8.086	115	415				55	755	300	1,350		
4 hours	8.226	117	428				50	805	300	4,650		
4¼ hours	8.226	117	413				50	855	300	4,950		
4½ hours	8.015	114	410	11.4	5.8	0.2	50	905	300	5,250		
4¾ hours	7.523	107	390				50	955	200	5,460		4 43
5 hours	7.312	104	380				50	1,005	250	5,700		
5¼ hours	8.226	117	385				50	1,055	300	6,000		
5½ hours	7.875	112	395				50	1,105	300	6,300		
5¾ hours	8.507	121	430				50	1,155	300	6,600		
6 hours	7.875	112					19.4	1,174.4	100	6,700		6 00
Total	197.640	2,812	9,384				1,174.4		6,700			
Average	7.906	112.5	391				48.9		279			

TABLE IV.—*Observations in detail of the tests of coals*—Continued.

E.—SECOND TEST OF COAL FROM LICHZOW VALLEY, AUSTRALIA—60 FIRINGS DURING 6¾-HOUR TEST.

[Test No. 5, Table II.]

Time after starting.	Steam pressure gauge. Kilos per square centimeter.	Steam pressure gauge. Pounds per square inch.	Temperature of flue gases, base of stack.	Average composition of flue gases, in per cent. CO_2	O_2	CO	Kilos of coal burned— During period.	Kilos of coal burned— Total.	Kilos of water fed to boiler— During period.	Kilos of water fed to boiler— Total.	Fire raked or sliced, time after starting.	Cleaned fire, time after starting.
											h. m.	*h. m.*
Beginning	7.031	100	320									0 00
¼ hour	7.101	101	325				60	60	300	300		
½ hour	7.453	106	385				55	115	300	600		
¾ hour	7.893	106	435				50	165	300	900	0 31	
1 hour	7.945	113	427				50	215	300	1,200		
1¼ hours	8.166	116	425				50	265	300	1,500		
1½ hours	7.312	104	435	11.8	3.4	0.4	50	315	200	1,700	1 21	
1¾ hours	7.242	103	445				50	365	200	1,900		
2 hours	7.242	103	470				50	415	200	2,100	1 19	
2¼ hours	7.804	111	517				50	465	200	2,300		
2½ hours	8.015	114	507				50	515	200	2,500		
2¾ hours	8.929	127	420				50	565	200	2,700		
3 hours	7.734	110	395				50	615	300	3,000		
3¼ hours	8.015	114	400				50	665	300	3,300		
3½ hours	7.523	107	397				50	715	300	3,600		
3¾ hours	7.453	106	395				50	765	300	3,900		
4 hours	7.734	110	400				50	815	300	4,200		3 52
4¼ hours	7.523	107	407				50	865	300	4,500		
4½ hours	7.453	106	400				50	915	300	4,800		
4¾ hours	7.242	103	390	10.2	8.0	0.2	50	965	300	5,100		
5 hours	7.664	109	365				50	1,015	300	5,400		
5¼ hours	7.523	107	360				50	1,065	300	5,700		
5½ hours	7.734	110	348				50	1,115	300	6,000		
5¾ hours	7.453	106	361				50	1,165	300	6,300		
6 hours	7.945	113	340				50	1,215	300	6,600		
6¼ hours	7.101	101	335				50	1,265	300	6,900	6 05	
6½ hours	6.961	99					50	1,315	300	7,200		
6¾ hours	7.101	101					19½	1,334½	117.6	7,317.6		6 42
Total	211.982	3,015	10,407				1,334½		7,317.6			
Average	7.571	107.7	400				49.4		271.			

TABLE IV.—*Observations in detail of the tests of coals*—Continued.

F.—TEST OF COAL FROM YOSHINOTANI (KARATSU), KIUSHU ISLAND, JAPAN—61 FIRINGS DURING 7-HOUR TEST.

[Test No. 6, Table II.]

Time after starting.	Steam pressure gauge.		Temperature of flue gases, base of stack.	Average composition of flue gases, in per cent.			Kilos of coal burned—		Kilos of water fed to boiler—		Fire raked or sliced, time after starting.	Cleaned fire, time after starting.
	Kilos per square centimeter.	Pounds per square inch.		CO_2	O_2	CO	During period.	Total.	During period.	Total.		
											h. m.	*h. m.*
Beginning	7.804	111	330									0 00
¼ hour	8.015	114	340				70	70	200	200		
½ hour	8.015	114	333				70	140	200	400		
¾ hour	7.945	113	320				60	200	250	650		
1 hour	7.734	110	270				60	260	250	900		
1¼ hours	7.875	112	335				60	320	250	1,150		
1½ hours	7.523	107	359	11.2	5.4	0.6	60	380	300	1,450		
1¾ hours	7.875	112	325				60	440	300	1,750	1 45	
2 hours	7.875	112	338				60	500	300	2,050		
2¼ hours	7.875	112	385				60	560	300	2,350		
2½ hours	8.015	114	360				60	620	300	2,650		
2¾ hours	7.523	107	335				60	680	300	2,950		
3 hours	7.453	106	310				60	740	0	2,950		2 49
3¼ hours	8.015	114	325				60	800	250	3,200		
3½ hours	7.593	108	285				60	860	250	3,450		
3¾ hours	8.015	114	345				60	920	300	3,750		
4 hours	7.945	113	335	11.2	4.6	0.4	60	980	300	4,050		
4¼ hours	7.593	108	320				60	1,040	300	4,350		
4½ hours	7.945	113	305				60	1,100	300	4,650		
4¾ hours	7.875	112	315				60	1,160	0	4,650		4 38
5 hours	7.875	112	325				60	1,220	250	4,900		
5¼ hours	8.367	119	355				60	1,280	250	5,150		
5½ hours	7.734	110	365				60	1,340	300	5,450		
5¾ hours	7.875	112	335				60	1,400	300	5,750		
6 hours	7.593	108	340	10.8	5.6	0.2	60	1,460	250	6,000		
6¼ hours	7.523	107	325				60	1,520	300	6,300		
6½ hours	7.875	112	346				60	1,580	300	6,600	6 16	
6¾ hours	8.086	115	365				54	1,634	100	6,700		6 33
7 hours	7.661	109	339				0	1,634	144	6,844		7 00
Total	227.100	3,230	9,665				1,634		6,844			
Average	7.830	111.4	333				58.4		244.3			

TABLE IV.—*Observations in detail of the tests of coals*—Continued.

G.—FIRST TEST OF COAL FROM YUBARI (HOKKAIDO PROVINCE) JAPAN—59 FIRINGS DURING 5-HOUR TEST.

[Test No. 7, Table II.]

Time after starting.	Steam pressure gauge.		Temperature of flue gases, base of stack.	Average composition of flue gases, in per cent.			Kilos of coal burned—		Kilos of water fed to boiler—		Fire raked or sliced, time after starting.	Cleaned fire, time after starting.
	Kilos per square centimeter.	Pounds per square inch.		CO_2	O_2	CO	During period.	Total.	During period.	Total.		
											h. m.	*h. m.*
Beginning	8.226	117	335									0 00
¼ hour	7.801	111	351				60	60	325	325		
½ hour	7.945	113	360				60	120	325	650		
¾ hour	8.086	115	351				55	175	325	975		
1 hour	8.437	120	350				55	230	325	1,300		
1¼ hours	8.086	115	380				55	285	325	1,625		
1½ hours	7.593	108	354				55	340	325	1,950		
1¾ hours	7.875	112	355	9.0	9.2	0.4	55	395	325	2,275		
2 hours	7.172	102	360				30	425	200	2,475		1 57
2¼ hours	7.312	104	370				60	485	325	2,800		
2½ hours	7.312	104	361				60	545	325	3,125		
2¾ hours	7.031	100	410				55	600	325	3,450	2 36 2 45	
3 hours	7.242	103	460				55	655	325	3,775		
3¼ hours	7.312	104	438				55	710	325	4,100		
3½ hours	7.804	111	445				55	765	325	4,425		
3¾ hours	8.156	116	448				55	820	325	4,750		
4 hours	7.875	112	451				55	875	325	5,075		
4¼ hours	7.806	111	460	5.0	13.0	0.6	55	930	325	5,400		
4½ hours	7.382	105	417				55	985	325	5,725		
4¾ hours	8.015	114	420				55	1,040	325	6,050		
5 hours	8.297	118	377				32.9	1,072.9	52	6,102		5 00
Total	162.766	2 315	8,295				1,072.9		6,102			
Average	7.750	110.2	395				53.6		305			

TABLE IV.—*Observations in detail of the tests of coals*—Continued.

II.—FIRST TEST OF COAL FROM LABUAN, BORNEO—112 FIRINGS DURING 7-HOUR TEST.

[Test No. 8, Table II.]

Time after starting.	Steam pressure gauge. Kilos per square centimeter.	Steam pressure gauge. Pounds per square inch.	Temperature of flue gases, base of stack.	Average composition of flue gases, in per cent. CO_2	Average composition of flue gases, in per cent. O_2	Average composition of flue gases, in per cent. CO	Kilos of coal burned— During period.	Kilos of coal burned— Total.	Kilos of water fed to boiler— During period.	Kilos of water fed to boiler— Total.	Fire raked or sliced, time after starting.	Cleaned fire, time after starting.
											h. m.	*h. m.*
Beginning	7.664	109	375									0 00
¼ hour	7.945	113	340				70	70	200	200		
½ hour	7.172	102	330				70	140	300	500		
¾ hour	7.523	107	340				60	200	300	800		
1 hour	7.382	105	380	11.8	6.0	----	50	250	300	1,100		
1¼ hours	7.172	102	375				50	300	300	1,400		
1½ hours	7.312	104	350				60	360	300	1,700		
1¾ hours	7.312	104	345				60	420	300	2,000		
2 hours	5.976	85	280				60	480	200	2,200		
2¼ hours	6.609	94	300				60	540	250	2,450		
2½ hours	6.258	89	365				60	600	200	2,650		
2¾ hours	5.484	78	315				60	660	200	2,850		
3 hours	5.273	75	235				60	720	200	3,050		
3¼ hours	5.625	80	320				60	780	200	3,250		3 16
3½ hours	5.341	76	325	11.5	3.5	----	75	855	200	3,450		
3¾ hours	5.625	80	400				75	930	200	3,650		
4 hours	5.765	82	400				75	1,005	250	3,900		
4¼ hours	6.328	90	410				75	1,080	350	4,250		
4½ hours	6.609	94	415				75	1,155	400	4,650	[b]4 19 [b]4 25	
4¾ hours	7.242	103	400				75	1,230	400	5,050	[b]4 39	
5 hours	7.593	108	425				75	1,305	400	5,450		
5¼ hours	7.312	104	410				75	1,380	400	5,850		
5½ hours	7.172	102	400				70	1,450	400	6,250		
5¾ hours	7.172	102	410				70	1,520	400	6,650		
6 hours	7.313	104	[a]450	8.6	7.2	----	70	1,590	400	7,050		
6¼ hours	7.801	111	[a]495				70	1,660	400	7,450		
6½ hours	7.312	104	[a]510				70	1,730	400	7,850		
6¾ hours	7.593	108	365				61	1,791	300	8,150		
7 hours	7.312	104	370				0	1,791	140	8,290		7 00
Total	198.202	2,819	10,935				1,791		8,290			
Average	6.831	97.2	377				64		296			

[a] This coal was unusually sooty, depositing enough on the tubes in this day's run to burn off at this time.

[b] This group represents the extravagance of a native fireman. Green coal was thrown onto the fire and then mixed with that already on the grate, causing much loss of fuel.

TABLE IV.—*Observations in detail of the tests of coals*—Continued.

I.—SECOND TEST OF COAL FROM LABUAN, BORNEO—113 FIRINGS DURING 6¾-HOUR TEST.

[Test No. 9, Table II.]

Time after starting.	Steam pressure gauge. Kilos per square centimeter.	Steam pressure gauge. Pounds per square inch.	Temperature of flue gases, base of stack.	Average composition of flue gases, in per cent. CO_2	O_2	CO	Kilos of coal burned— During period.	Kilos of coal burned— Total.	Kilos of water fed to boiler— During period.	Kilos of water fed to boiler— Total.	Fire raked or sliced, time after starting.	Cleaned fire, time after starting.
											h. m.	h. m.
Beginning	7.804	111	340									0 00
¼ hour	7.661	109	340				75	75	300	300		
½ hour	7.172	102	335				75	150	300	600		
¾ hour	7.172	102	350				65	215	280	880		
1 hour	7.523	107	350				65	280	280	1,160		
1¼ hours	7.593	108	375				65	345	280	1,440		
1½ hours	7.172	102	380	11.8	4.6		65	410	280	1,720		
1¾ hours	7.172	102	350				65	475	280	2,000		
2 hours	6.961	99	395				65	540	280	2,280		
2¼ hours	7.172	102	390				70	610	280	2,560		
2½ hours	7.172	102	[a]485				70	680	280	2,840	2 30	
2¾ hours	7.172	102	[a]485				70	750	280	3,120		
3 hours	6.961	99	[a]500				70	820	280	3,400		
3¼ hours	6.820	97	405				70	890	280	3,650		
3½ hours	6.820	97	395				70	960	280	3,960		3 30
3¾ hours	7.523	107	410				70	1,030	330	4,290		
4 hours	7.523	107	410				70	1,100	330	4,620		
4¼ hours	7.875	112	410				70	1,170	330	4,950		
4½ hours	7.523	107	375				70	1,240	330	5,280		
4¾ hours	7.875	112	370	12.3	3.1		70	1,310	330	5,610		
5 hours	7.382	105	400				70	1,380	330	5,940		
5¼ hours	7.664	109	375				70	1,450	330	6,270		
5½ hours	7.382	105	385				70	1,520	330	6,600		
5¾ hours	7.453	106	390				70	1,590	330	6,930		
6 hours	7.242	103	405				70	1,660	330	7,260	5 46	
6¼ hours	7.664	109	465				70	1,730	330	7,590		
6½ hours	7.593	108	400				61	1,791	330	7,920		
6¾ hours	7.172	102					0	1,791	164	8,084		6 40
Total	206.221	2,933	10,760				1,791		8,084			
Average	7.365	101.7	398.5				66.3		299			

[a] This coal was unusually sooty depositing enough on the tubes in a few hours to burn off at this time.

TABLE IV.—*Observations in detail of the tests of coals*—Continued.

K.—SECOND TEST OF COAL FROM THE MILITARY RESERVATION, BATAN ISLAND—64 FIRINGS DURING 7½-HOUR TEST.

[Test No. 11, Table II.]

Time after starting.	Steam pressure gauge. Kilos per square centimeter.	Steam pressure gauge. Pounds per square inch.	Temperature of flue gases, base of stack.	Average composition of flue gases, in per cent. CO_2	O_2	CO	Kilos of coal burned— During period.	Total.	Kilos of water fed to boiler— During period.	Total.	Fire raked or slieed, time after starting.	Cleaned fire, time after starting
											h. m	h. m.
Beginning	8.367	119	310									0 00
¼ hour	7.945	113	315				60	60	225	225		
½ hour	7.664	109	305				60	120	225	450		
¾ hour	7.664	109	305				60	180	225	675		
1 hour	7.734	110	315	7.8	7.6	0.6	60	240	225	900		
1¼ hours	7.731	110	360				60	300	225	1,125	1 07	
1½ hours	7.875	112	305				60	360	225	1,350		
1¾ hours	7.875	112	340				60	420	225	1,575		
2 hours	7.593	108	320				60	480	225	1,800	1 50	
2¼ hours	7.731	110	300				60	540	225	2,025		
2½ hours	7.874	110	300				60	600	200	2,225		2 26
2¾ hours	7.172	102	282				60	660	225	2,450		
3 hours	7.804	111	315				60	720	225	2,675		
3¼ hours	7.875	112	315				55	775	200	2,875		
3½ hours	8.226	117	290	7.5	7.3	0.9	55	830	200	3,075		
3¾ hours	7.523	107	300				55	885	200	2,275		
4 hours	7.945	113	290				55	940	200	3,475	3 54	
4¼ hours	7.664	109	310				55	995	200	3,675		
4½ hours	7.875	112	320				55	1,050	200	3,875		
4¾ hours	7.382	105	288				55	1,105	200	4,075		
5 hours	7.945	113	310				55	1,160	200	4,275		
5¼ hours	7.664	109	300				55	1,215	200	4,175		
5½ hours	8.015	111	310				55	1,270	200	4,675		
5¾ hours	7.734	110	288				55	1,325	200	1,875		
6 hours	7.523	107	310	8.2	6.2	1.1	55	1,380	200	5,075		
6¼ hours	7.804	111	300				55	1,435	200	5,275		
6½ hours	7.731	110	300				55	1,490	200	5,475		
6¾ hours	7.523	107	310				55	1,545	200	5,675		
7 hours	7.734	110	310				42.6	1,587.6	158	5,833		
7½ hours							0	1,587.6	0	5,833		7 05
Total	225.061	3,201	8,983				1,587.6		5,833			
Average	7.761	110.4	310				56.7		208.3			

TABLE IV.—*Observations in detail of the tests of coals*—Continued.

L.—THIRD TEST OF COAL FROM THE MILITARY RESERVATION, BATAN ISLAND—56 FIRINGS DURING 7-HOUR TEST.

[Test No. 12, Table II.]

Time after starting.	Steam pressure gauge.		Temperature of flue gases, base of stack.	Average composition of flue gases, in per cent.			Kilos of coal burned—		Kilos of water fed to boiler—		Fire raked or sliced, time after starting.	Cleaned fire, time after starting.
	Kilos per square centimeter.	Pounds per square inch.		CO_2	O_2	CO	During period.	Total.	During period.	Total.		
											h. m.	*h. m.*
Beginning	7.804	111	300									0 00
¼ hour	7.664	109	330				60	60	225	225		
½ hour	7.734	110	330				60	120	225	450		
¾ hour	7.945	113	345				60	180	225	675	0 43	
1 hour	7.945	113	355				60	240	225	900		
1¼ hours	7.875	112	330				60	300	225	1,125		
1½ hours	7.664	109	315				60	360	225	1,345		
1¾ hours	7.875	112	320	5.0	8.0	1.4	60	420	225	1,575		
2 hours	7.804	111	290				60	480	225	1,800		
2¼ hours	8.015	114	285				60	540	225	2,025		
2½ hours	7.312	104	435				60	600	225	2,250		
2¾ hours	8.015	114	380				55	655	225	2,475		
3 hours	7.875	112	345				55	710	225	2,700		
3¼ hours	8.086	115	320				55	765	225	2,925		
3½ hours	7.875	112	350				55	820	225	3,150		
3¾ hours	7.945	113	310				55	875	225	3,375		
4 hours	7.382	105	290				55	930	200	3,575		
4¼ hours	8.297	118	350				55	985	200	3,775		
4½ hours	7.312	104	340				55	1,040	200	3,975		
4¾ hours	7.875	112	315				55	1,095	200	4,175		
5 hours	8.015	114	330				55	1,150	200	4,375		
5¼ hours	7.623	107	300				55	1,205	200	4,575		
5½ hours	7.664	109	325	8.8	6.8	0.4	55	1,260	200	4,775		
5¾ hours	7.734	110	380				55	1,315	200	4,975		5 35
6 hours	7.523	107	390				55	1,370	200	5,175		
6¼ hours	7.664	109	340				55	1,425	200	5,375	6 03 6 12	
6½ hours	7.593	108	335				55	1,480	200	5,575	6 25	
6¾ hours	7.664	109	365				55	1,535	200	5,775	6 35	
7 hours	7.382	105	340				27.6	1,562.6	178	5,953		7 00
Total	225.061	3,201	9,690				1,562.6		5,953			
Average	7.761	110.4	334				53.8		212.6			

TABLE IV.—*Observations in detail of the tests of coals*—Continued.

M.—FIRST TEST OF LUMP COAL FROM THE MILITARY RESERVATION, BATAN ISLAND—76 FIRINGS DURING 7-HOUR TEST.

[Test No. 13, Table II.]

Time after starting.	Steam pressure gauge.		Temperature of flue gases, base of stack.	Average composition of flue gases, in per cent.			Kilos of coal burned—		Kilos of water fed to boiler—		Fire raked or sliced, time after starting.	Cleaned fire time after starting.
	Kilos per square centimeter	Pounds per square inch.		CO_2	O_2	CO	During period.	Total.	During period.	Total.		
											h. m.	h. m.
Beginning	7.172	102	------				------	------	------	------	------	0 00
¼ hour	7.664	109	------				65	65	310	310	------	------
½ hour	7.664	109	405				60	125	310	620	------	------
¾ hour	7.593	108	395				60	185	310	930	------	------
1 hour	7.523	107	430				60	245	310	1,240	0 55	------
1¼ hours	7.804	111	410	11.6	6.2	0.6	60	305	310	1,550	------	------
1½ hours	7.523	107	450				60	375	310	1,860	------	------
1¾ hours	7.382	105	445				55	430	310	2,170	------	------
2 hours	7.734	110	448				55	485	310	2,480	------	------
2¼ hours	7.664	109	397				55	540	310	2,790	------	------
2½ hours	7.453	106	430				60	600	310	3,100	------	2 25
2¾ hours	7.242	103	442				60	660	310	3,410	------	------
3 hours	7.523	107	465				55	715	310	3,720	------	------
3¼ hours	7.382	105	440				55	770	310	4,030	------	------
3½ hours	7.523	107	455	11.0	7.2	0.4	55	825	310	4,340	------	------
3¾ hours	7.734	110	420				55	880	310	4,650	------	------
4 hours	8.226	117	405				55	935	310	4,960	------	------
4¼ hours	7.875	112	378				55	990	310	5,270	------	------
4½ hours	8.307	118	385				55	1,045	310	5,580	------	------
4¾ hours	7.382	105	370				55	1,100	310	5,890	------	------
5 hours	7.915	113	385				55	1,155	310	6,200	------	------
5¼ hours	7.804	111	400				50	1,205	310	6,510	------	5 15
5½ hours	7.312	104	400				60	1,265	310	6,820	------	------
5¾ hours	7.523	107	380	10.3	7.3	0.8	60	1,325	310	7,130	------	------
6 hours	8.507	121	390				55	1,380	310	7,440	------	------
6¼ hours	8.015	114	400				55	1,435	310	7,750	------	------
6½ hours	7.664	109	412				55	1,490	310	8,060	------	------
6¾ hours	7.664	109	415				55	1,545	310	8,370	------	------
7 hours	7.242	103	432				27.5	1,572.5	198	8,568	------	7 00
Total	220.016	3,158	11,194	------	------	------	1,572.5	------	8,568	------	------	------
Average	7.656	108.9	414⅔	------	------	------	56.1	------	306	------	------	------

TABLE IV.—*Observations in detail of the tests of coals*—Continued.

N—SECOND TEST OF LUMP COAL FROM THE MILITARY RESERVATION, BATAN ISLAND—89 FIRINGS DURING 6⅚-HOUR TEST.

[Test No. 14, Table II.]

Time after starting.	Steam pressure gauge. Kilos per square centimeter.	Steam pressure gauge. Pounds per square inch.	Temperature of flue gases, base of stack.	Average composition of flue gases, in per cent. CO_2	O_2	CO	Kilos of coal burned— During period.	Kilos of coal burned— Total.	Kilos of water fed to boiler— During period.	Kilos of water fed to boiler— Total.	Fire raked or sliced, time after starting.	Cleaned fire, time after starting.
											h. m.	*h. m.*
Beginning.	8.156	116	400								(a)	0 00
¼ hour	7.731	110	430				60	60	300	300		
½ hour	8.086	115	430				55	115	300	600		
¾ hour	8.086	115	430				52	167	300	900		
1 hour	7.664	109	388				52	219	300	1,200		
1¼ hours	7.664	109	392				52	271	300	1,500		
1½ hours	7.664	109	408	10.0	7.4	0.2	52	323	300	1,800		
1¾ hours	8.437	120	426				52	375	300	2,100		
2 hours	7.804	111	393				52	427	300	2,400		
2¼ hours	7.945	113	380				52	479	300	2,700		
2½ hours	7.382	105	375				52	531	300	3,000		
2¾ hours	7.593	108	410				52	583	300	3,300		
3 hours	7.664	109	400				52	635	300	3,600		
3¼ hours	8.015	114	370				52	687	300	3,900		
3½ hours	7.804	111	389				52	739	300	4,200		
3¾ hours	8.015	114	400				52	791	300	4,500		
4 hours	8.086	115	350				52	843	300	4,800		
4¼ hours	8.156	116	344				52	895	300	5,100		
4½ hours	7.875	112	402				52	947	300	5,400		
4¾ hours	8.086	115	380				52	999	300	5,700		
5 hours	8.015	114	386	8.0	10.6	0.0	52	1,051	300	6,000		
5¼ hours	7.664	109	372				52	1,103	300	6,300		
5½ hours	7.382	105	390				52	1,155	300	6,600		
5¾ hours	7.523	107	380				52	1,207	300	6,900		
6 hours	8.367	119	381				52	1,259	300	7,200		
6¼ hours	7.664	109	397				52	1,311	300	7,500		
6½ hours	8.015	114	385				52	1,363	300	7,800		
6¾ hours	7.734	110	365				41.3	1,404.3	185	7,985		
6⅚ hours	7.731	110					0	1,404.3	0	7,985		6 50
Total	228.014	3,243	10,986				1,404.3		7,985			
Average	7.862	111.8	392.4				51.4		292			

a The fire on the grate was not disturbed during the entire run.

TABLE IV.—*Observations in detail of the tests of coals*—Continued.

O.—FIRST TEST OF COAL FROM BETTS' MINE, BATAN ISLAND—66 FIRINGS DURING 4-HOUR TEST.

[Test No. 15, Table II.]

Time after starting.	Steam pressure gauge. Kilos per square centimeter.	Steam pressure gauge. Pounds per square inch.	Temperature of flue gases, base of stack.	Average composition of flue gases, in per cent. CO_2	O_2	CO	Kilos of coal burned— During period.	Total.	Kilos of water fed to boiler— During period.	Total.	Fire raked or slic-ed, time after starting.	Cleaned fire, time after starting.
											h. m.	*h. m.*
Beginning	6.187	85	440									0 00
¼ hour	5.765	82	465				75	75	275	275		
½ hour	5.765	82	412	11.1	7.4	0.0	75	150	275	550		
¾ hour	5.273	75	403				75	225	275	825	0 45	
1 hour	5.203	74	510				75	300	275	1,100		
1¼ hours	5.273	75	520				75	375	275	1,375		
1½ hours	5.062	72	480	14.2	4.0	0.0	75	450	275	1,650		
1¾ hours	4.851	69	450				75	525	275	1,925	1 45	
2 hours	4.008	57	430				75	600	275	2,200		
2¼ hours	3.937	56	425				75	675	275	2,475		
2½ hours	4.078	58	415	11.8	6.4	0.2	75	750	275	2,750		
2¾ hours	4.008	57	405				70	820	275	3,025	2 45	
3 hours	3.867	55	360				70	890	275	3,300		
3¼ hours	3.656	52	393				70	960	275	3,575		
3½ hours	3.164	45	292	7.8	10.0	0.8	70	1,030	275	3,850		
3¾ hours	2.953	42	250				70	1,100	275	4,125		
4 hours	2.953	42	250				34	1,134	186	4,311		4 00
Total	76.003	1,081	6,900				1,134		4,311			
Average	4.471	63.6	406				70.9		269.4			

TABLE IV.—*Observations in detail of the tests of coals*—Continued.

P.—SECOND TEST OF COAL FROM BETTS' MINE, BATAN ISLAND—125 FIRINGS DURING 7-HOUR TEST.

[Test No. 16, Table II.]

Time after starting.	Steam pressure gauge.		Temperature of flue gases, base of stack.	Average composition of flue gases, in per cent.			Kilos of coal burned—		Kilos of water fed to boiler—		Fire raked or sliced, time after starting.	Cleaned fire, time after starting.
	Kilos per square centimeter.	Pounds per square inch.		CO_2	O_2	CO	During period.	Total.	During period.	Total.		
											h. m.	h. m.
Beginning	7.382	105	430									0 00
¼ hour	7.875	112	455				85	85	325	325		
½ hour	6.961	99	455				85	170	325	650		
¾ hour	7.453	106	480				85	255	325	975		
1 hour	7.031	100	460	10.9	6.9	0.0	85	340	325	1,300		
1¼ hours	7.172	102	450				85	425	325	1,625		
1½ hours	6.539	93	440				85	510	325	1,950		
1¾ hours	6.609	94	415				50	560	225	2,175		1 45
2 hours	7.031	100	410				100	660	300	2,475		
2¼ hours	7.593	108	420				85	745	325	2,800		
2½ hours	7.172	102	430				85	830	325	3,125		
2¾ hours	7.172	102	425				85	915	325	3,450		
3 hours	7.382	105	430				85	1,000	325	3,775	2 51	
3¼ hours	7.453	106	430				85	1,085	325	4,100	3 07	
3½ hours	7.661	109	440	10.6	7.4	0.6	85	1,170	325	4,425		
3¾ hours	7.593	108	445				85	1,255	325	4,750	3 31	
4 hours	7.801	111	440				85	1,340	325	5,075		
4¼ hours	7.523	107	400				85	1,425	325	5,400		
4½ hours	7.242	103	365				85	1,510	325	5,725		
4¾ hours	7.661	109	430				85	1,595	325	6,050		
5 hours	7.734	110	405				85	1,680	325	6,375	5 00	
5¼ hours	7.523	107	435				85	1,765	325	6,700	5 14	
5½ hours	7.453	106	430				85	1,850	325	7,025		
5¾ hours	7.945	113	435				85	1,935	325	7,350		
6 hours	7.453	106	450	11.0	7.4	0.0	85	2,020	325	7,675	6 00	
6¼ hours	7.661	100	430				85	2,105	325	8,000		
6½ hours	7.382	105	480				85	2,190	325	8,325	6 23	
6¾ hours	7.523	107	490				85	2,275	325	8,650	6 34	
7 hours	6.890	98	505				38.4	2,313.4	112	8,762		7 00
Total	213.882	3,012	12,760				2,313.4		8,762			
Average	7.375	101.9	440				82.6		313			

TABLE IV.—*Observations in detail of the tests of coals*—Continued.

Q.—FIRST TEST OF COAL FROM THE COMANSI MINE, NEAR DANAO, CEBU—61 FIRINGS DURING 5¾-HOUR TEST.

[Test No. 17, Table II.]

Time after starting.	Steam pressure gauge. Kilos per square centimeter.	Steam pressure gauge. Pounds per square inch.	Temperature of flue gases, base of stack.	Average composition of flue gases, in per cent. CO_2	Average composition of flue gases, in per cent. O_2	Average composition of flue gases, in per cent. CO	Kilos of coal burned— During period.	Kilos of coal burned— Total.	Kilos of water fed to boiler— During period.	Kilos of water fed to boiler— Total.	Fire raked or sliced, time after starting.	Cleaned fire, time after starting
											h. m.	*h. m.*
Beginning	6.961	99	325				57					0 00
¼ hour	7.593	108	385				57	57	290	290		
½ hour	8.015	114	400				57	114	290	580		
¾ hour	7.453	106	385				57	171	290	870		
1 hour	7.312	104	400	9.0	6.5	2.0	57	228	290	1,160		
1¼ hours	7.593	108	495				57	285	290	1,450		
1½ hours	7.242	103	430				57	342	290	1,740		
1¾ hours	7.523	107	390				57	399	290	2,030		
2 hours	7.312	104	385				57	456	290	2,320		
2¼ hours	7.804	111	400				57	513	290	2,610		
2½ hours	7.664	109	455				57	570	290	2,900		
2¾ hours	7.503	108	375				57	627	290	3,190		
3 hours	7.453	106	390				57	684	290	3,480		
3¼ hours	7.172	102	330	10.0	7.6	0.4	57	741	290	3,770		
3½ hours	8.086	115	390				57	798	290	4,060		3 25
3¾ hours	8.015	114	450				57	855	290	4,350		
4 hours	7.382	105	380				57	912	290	4,640		
4¼ hours	7.804	111	360				57	969	290	4,930		
4½ hours	7.453	106	370				57	1,026	290	5,220		
4¾ hours	7.453	106	375				57	1,083	290	5,510		
5 hours	7.664	109	350	10.2	5.4	2.0	57	1,140	290	5,800		
5¼ hours	7.453	106	375				57	1,197	290	6,090		
5¾ hours	7.593	108	375				30.4	1,227.4	146.6	6,236.6		5 30
Total	173.593	2,469	8,970				1,227.4		6,236.6			
Average	7.547	107.3	390				55.8		283.4			

TABLE IV.—*Observations in detail of the tests of coals*—Continued.

R.—SECOND TEST OF COAL FROM THE COMANSI MINE, NEAR DANAO, CEBU—68 FIRINGS DURING 7½-HOUR TEST.

[Test No. 18, Table II.]

Time after starting.	Steam pressure gauge.		Temperature of flue gases, base of stack.	Average composition of flue gases, in per cent.			Kilos of coal burned—		Kilos of water fed to boiler—		Fire raked or sliced, time after starting.	Cleaned fire, time after starting.
	Kilos per square centimeter.	Pounds per square inch.		CO_2	O_2	CO	During period.	Total.	During period.	Total.		
											h. m.	h. m.
Beginning	7.523	107	325									0 00
¼ hour	7.875	112	355				60	60	260	260		
½ hour	8.066	115	345				60	120	260	520		
¾ hour	7.945	113	330				55	175	260	780		
1 hour	7.453	106	330				55	230	260	1,040		
1¼ hours	7.875	112	360				55	285	260	1,300		
1½ hours	7.593	108	360				55	340	260	1,560		
1¾ hours	8.015	114	330			(a)	55	395	260	1,820		
2 hours	7.734	110	355				52	447	260	2,080		
2¼ hours	7.453	106	330				52	499	260	2,340		
2½ hours	8.015	114	315				52	551	260	2,600		
2¾ hours	7.593	108	325				52	603	260	2,860		
3 hours	7.593	108	330				52	655	260	3,120		
3¼ hours	7.382	105	315				52	707	260	3,380		
3½ hours	7.945	113	330				52	759	260	3,640		
3¾ hours	7.453	106	330				52	811	260	3,900		
4 hours	7.875	112	495				52	863	260	4,160		
4¼ hours	7.945	113	415				52	915	260	4,420		
4½ hours	7.875	112	325				52	967	260	4,680		
4¾ hours	8.367	119	350				52	1,019	260	4,940		
5 hours	7.945	113	320				52	1,071	260	5,200		
5¼ hours	7.523	107	315				52	1,123	260	5,460		
5½ hours	7.453	106	320				52	1,175	260	5,720		
5¾ hours	7.664	109	315			(a)	52	1,227	260	5,980		
6 hours	7.382	105	310				52	1,279	260	6,240		
6¼ hours	7.664	109	345				52	1,331	260	6,500		
6½ hours	7.523	107	330				52	1,383	260	6,760	6 30	
6¾ hours	7.664	109	350				52	1,435	260	7,020		
7 hours	7.593	108	365				52	1,487	260	7,280		
7¼ hours	7.382	105	365				52	1,539	260	7,540		
7½ hours	7.523	107	327				27	1,566	131½	7,671½		7 30
Total	238.911	3,398	10,612				1,566		7,671½			
Average	7.706	109.6	342				52.2		255.7			

a High.

DISCUSSION.

The data sustain the conclusions that the value of a coal for producing steam in an ordinary boiler is determined not only by its fuel ratio and by the total number of heat units set free during its complete combustion, but it is also dependent largely upon other and variable factors.

Impurities in the coal.—The purity of the coal—that is, the admixture of earthy matter, moisture and other foreign material which it contains—is an important consideration. If the percentage of ash and water is small the theoretical heat value of the coal is proportionally increased and from a commercial standpoint the original cost of freight and handling per thermal unit and the expense of removing the ash as well is correspondingly decreased. These items represent a direct saving. Moreover, with coals high in moisture the efficiency is lowered directly by the specific heat of the water.

The color of the ash indicates the iron content and is also usually taken as an indication as to whether or not the coal will clinker. However, iron is but one constituent and other factors enter in just as they influence the fusion point of clay [12] or cement. As comparatively few coals burn without forming clinker, it is interesting to note that in many of the tests of Philippine coal, in particular the tests of the coal from the military reservation, Batan Island, where the percentage of ash is high and it is brick-red, very little clinker was produced. It is probable that the ash bed in this non-coking, highly volatile coal is not heated sufficiently high to form clinker. The distillation of volatile matter is endothermic and therefore the explanation of the lack of clinker is probably partly to be found in the fact that the distillation of this large percentage of volatile matter keeps the temperature of the fuel bed low. Furthermore, in a non-coking coal the lumps are thoroughly disintegrated with the expulsion of the volatile matter and the ash kept cool by the air and gases passing through and around its particles. If the same ash were in a coking coal it would be held in the lump and probably be heated hot enough on the grate and in the fuel bed to melt it and produce clinker.

It is believed that a reasonable amount of ash has little influence on efficiency other than the amount of combustible carried away, except where it interferes mechanically. If a coal clinkers and tends to close the air spaces it greatly increases the labor in connection with its consumption and entails a loss of heat through the furnace doors through frequent opening to work the fires. On the other hand, although clinker

[12] Cox, A. J.: The occurrence, composition and radioactivity of the clays from Luzon, P. I., *This Journal, Sec. A.* (1907), 2, 427.

may hinder combustion, it prevents fine coal from falling through the grate and in this way may partially compensate for its inconvenience. The finer and dirtier coal from Batan Island after correcting for loss of fine coal (i. e., calculated to coal actually burned), and the difference in ash content, gave somewhat lower efficiencies than the larger and carefully selected sizes. The only apparent difference in the behavior and quality of the various sizes is that the fine coal, high in ash, tends slightly to smother the fire and steam can not be produced at as great a rate as with the larger sizes. An inspection of Table II shows that the first test of the coal from the military reservation with the highest percentage of ash has a less evaporation per unit of combustible actually consumed than the second and third, which contain less ash, and still less than the fourth and fifth which contain still less ash. The variation, however, is not believed to be due to the ash, but is largely accounted for far more easily by a consideration of the fuel ratio, i. e., $\frac{\text{fixed carbon}}{\text{volatile combustible matter}}$, the greater ratio giving the greater efficiency; although that very high ash may reduce the draft, cause a slower rate of combustion and therefore less complete combustion in the furnace chamber and the range of the water tubes is not without reason.

Fire box and grate.—This Bureau has what is ordinarily considered to be a good boiler plant. However, it has a short fire box and only the usual vertical baffling and this is not sufficient to enable it to be run without some black smoke and loss. It is a recognized fact that the loss of heat due to the actual carbon in the escaping gases is small, perhaps never more than 1 per cent, but smoke is a strong indication of the presence of combustible gases the loss of which may amount to several per cent and materially impair the efficiency.

A short fire box is not at all suited successfully to burn Philippine coal. I have often urged [13] the necessity of a setting with an elongated fire box and combustion chamber for burning this class of coal. The combustion space must be long and large enough for the combustible gases and air to mix thoroughly and to produce complete combustion. The United States Geological Survey has expressed the same opinion and further lays special emphasis on the necessity of an additional baffle wall.[14] Such a wall would undoubtedly cause more perfect mixing and therefore more perfect combustion, which is the desired end. It is probable that eddies such as one seeks to attain in a reverberatory furnace, caused by any obstacle in the path of the gases, greatly aid the mixing. Any scheme which works in the direction of retarding the

[13] Cox, A. J.: *This Journal* (1906), 1, 877; *Sec. A.* (1907), 2, 41.
[14] *U. S. G. S. Bull.* (1907), 325, 62.

exit of the gases of the flame stream until combustion of the volatile combustible matter is completed in the combustion chamber, contains the possibility of greatly increasing the efficiency of Philippine coals. Satisfactory baffle walls would probably be of as much value as a considerable increase in the length of the fire box. A boiler with the same setting as those of this Bureau, but arranged with different baffling forming a tile-roof furnace, has been used on Illinois coals and is said to run at capacities of from 50 to 100 per cent without smoke.[15]

Various grates other than the ordinary bar have been suggested and tried on coals of the sub-bituminous variety. It was hoped that the perforated grate would be more economical of coal. However, in the tests of Mr. Betts' coal there was a slight incipient clinker which could not be dislodged from the holes and the steam pressure fell at the end of the test because of lack of draft. It was not possible to experiment much with this coal beforehand and but little information regarding it could be obtained. The grate worked well with Australian coal. With more experience and slight modifications this may still be more satisfactory than the ordinary grates. Mr. Betts has tried a herring-bone grate which he reports to be very successful. The advantage of a grate of this type over the ordinary gridiron is that shorter, thinner and more bars may be used without danger of their melting down and in this way the air spaces increased in number, but diminished in size without changing the ratio between air space and grate surface. It has also been suggested that the loss of combustible matter in the ash could be prevented by burning these coals on a rocking grate. It is hoped that the study of the behavior of Philippine coal and coals of this class will soon result in the discovery of a more satisfactory grate and a method of combustion that will be more economical of the coal.

Reconstruction of the present boiler settings in the Archipelago is out of the question. Greater efficiency, therefore, can be obtained only by building additional baffle walls, using a more satisfactory grate, elongating the fire box or heating the air before entering the grate, and these improvements from an economic standpoint can best be tried in the order of enumeration.

[15] Breckenridge, L. P.: *Univ. of Ill. Bull.* (1906), **4**, No. 31, 22. M. Ernest Schmidt, *Bull. soc. ind. d'Amiens*, **2–3**, 102; *C. A.* (1908), **2**, 174, has called attention to the fact that it is difficult to destroy smoke after it is once formed, but believes in preventing its formation by gradual introduction of coal into the fire box, if possible under the burning combustible, and finally, by the use of a mass of fire brick kept at a high temperature. He also considers the heating of the air before entering the grate necessary. In the combustion of Philippine coal where high chimney temperatures are obtained this might be accomplished by a down-draft pipe through the stack.

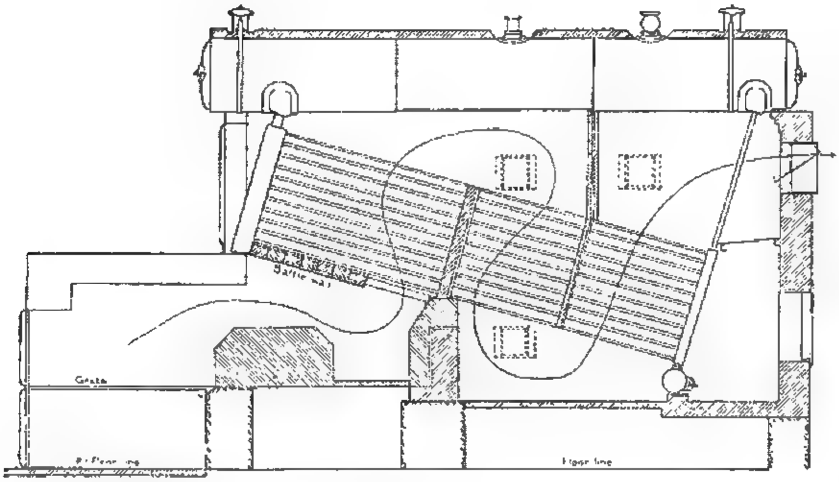


FIG. 2.—IDEAL SECTION SHOWING ADDITIONAL BAFFLE WALL AND AN ELONGATED FIRE BOX.

In the plant of this Bureau, Australian coal burns to a large extent on the grate, while most of the Philippine non-coking coals containing high volatile matter are at a disadvantage, as they burn to a very much greater extent in the combustion chamber. An inspection of the foregoing tests of the coals from Australia (Westwaldsend), Batan Island (Military Reservation and Betts'), and Cebu (Comansi) will show that our boiler-plant is unfavorable to Philippine coal. This may the more readily be seen from the following table:

TABLE V.

Source.	Calorific value of the combustible in calories as determined in a Berthelot-Mahler bomb calorimeter.	Equivalent evaporation of water from and at 100° C. per kilo of combustible actually consumed.	Equivalent evaporation of water from and at 100° C. per kilo of combustible actually consumed, anticipated from the calorific value when Australian coal is taken as the base of comparison.
Australian: (Westwaldsend); average of tests 1, 2, and 3, Table II	7,791	8,088	8,688
Batan Island:			
Military reservation; average of tests 10, 11, 12, 13, and 14, Table II	7,166	6,773	8,000
Betts'; average of tests 15 and 16, Table II	6,297	6,608	7,020
Cebu (Comansi); average of tests 17 and 18, Table II	7,207	7,122	8,040
Polillo; test 19, Table II	7,358		8,210

Coals which burn low and close to the grate give greatest efficiencies; those which burn high lose much through the grate, give low initial temperature in the fire box, leaving the fuel bed comparatively cool, and the result is combustion at the rear of the chamber, imperfect heat absorption and therefore low efficiency. I think this loss is largely due to the type of boiler, and one should be constructed for these coals that would obviate these losses. I should like to be in a position absolutely to name the best class of furnace for each coal, but not enough tests have been carried on to enable me to do so; however, considerable information as to the best form of furnace has been given.

Loss through the grate.—A portion of the combustible matter of the coal falls through the grate into the ash pit and is not burned. For a definite coal this varies with the grate and for a certain grate it varies with the coal. It is a most difficult task, not yet accomplished, to construct a grate that is suitable under any and all conditions of operation. Owing to my inability to have a grate suitable for each coal this discrepancy is much larger in some cases than in others, and therefore I have given, in addition to the usual data, recalculated results to show the values when this factor is eliminated, i.e., as if this amount of coal had never been fired.

Draft, chimney gases and loss through the stack.—Draft, measured by the reduction of pressure as compared with that of the atmosphere, which depends on the relation of boiler, furnace, grate and stack, largely controls the air which enters and the value of the fuel is influenced by it to a marked extent. However, in a boiler plant in the tropics much depends on the direction of the wind, since in most cases the boiler is not protected at the sides. Too much air is better than too little; on the other hand, an excessive amount dilutes the gases, lowers their temperature and increases the waste to the stack by an amount equal to the specific heat of the moisture from the excess of air and the heat carried away by the additional quantity of dry chimney gases. The loss up the chimney decreases and the efficiency rises with a reduction in the supply of air until a point is reached at which the loss due to slightly incomplete combustion is just equal to the gain obtained by decreased loss to the stack. Beyond this point the decrease in efficiency is very rapid. It has been my aim to regulate the air supply as much as possible without reducing the completeness of combustion, and in that way I endeavored to control the quantity of gases leaving the system and therefore the waste heat. Without experience with a given coal it is not always possible accurately to supply the proper amount of air for its ideal combustion. It may be noticed from an examination of the tests that a certain amount of carbon monoxide was observed in the chimney gases. This amount was greatest in those from the coal from

the Comansi mine at Danao, Cebu (test 17) where there was an abnormal waste to the stack and the efficiency recorded is therefore probably somewhat low.

It has been shown[16] that any considerable percentage of carbon monoxide is threatening to efficiency. Owing to the infiltration of an unknown quantity of air no exact limit could be set to this, but since the presence of carbon monoxide may also be taken as an indication of other incomplete combustion losses, high carbon monoxide is a prominent danger signal. It has also been shown[17] that the furnace efficiency drops very rapidly after the carbon dioxide content in the flue gases has reached about 9 per cent or perhaps 12 per cent if the gas has not been diluted by leaks. From a knowledge of the law of mass action one would expect, where the oxygen content is low and the carbon dioxide high, that some carbon would only be partially oxidized, that is, the presence of some carbon monoxide would be probable; however, an equilibrium may not always be attained in the combustion chamber. As the flue gases passed the sampler in the seventeenth test the oxygen content was higher and carbon dioxide lower than in the tenth where combustion was complete. Such a condition as that in the seventeenth, where the gas analyses represent the average of a period, might be produced by careless stoking so spasmodic that at times the percentage of oxygen would be small, with incomplete combustion, and at other times so large, that the average oxygen content would be increased. However, I do not believe that this is the case in this series. An explanation which suggests itself is that each individual coal, at any given temperature, may require a certain excess of oxygen, varying with the complexity of the hydrocarbon compounds, to effect complete decomposition of the coal gases. If the latter pass the high temperature of the furnace undecomposed, then the small supply of oxygen is not sufficient to effect combustion before they escape from the combustion chamber.

Furthermore, owing to the coolness of the fuel bed and combustion chamber when highly volatile coals are burned, combustion takes place slowly and it is not surprising that the carbon monoxide and other combustible gases are swept on and cooled below their ignition temperatures before combustion is complete.

The corrected ignition temperatures of various molecular relations of hydrogen and carbon monoxide, with oxygen are the following:[18]

$4H_2+O_2=605°$	$6CO+O_2=721°$
$2H_2+O_2=540°$	$4CO+O_2=628°$
$H_2+O_2=514°$	$2CO+O_2=601°$
$H_2+2O_2=530°$	$CO+O_2=631°$
$H_2+4O_2=571°$	

[16] *U. S. G. S. Bull.* (1907), 325, 65.

[17] *Ibid.* 51.

[18] K. G. Falk, *Ann. d. Phys.* (1907) (4), 24, 450.

The introduction of an inert gas such as the nitrogen content of the combustion chamber, greatly raises the ignition temperature and for the bimolecular reaction between hydrogen and oxygen it is increased according to the equation

$$T=T'+30\ n$$

where

$$n=\frac{\text{volume of the nitrogen } (N_2)}{\text{volume of the hydrogen } (H_2) \text{ or the oxygen } (O_2)}$$

whichever is present in the smallest quantity. For the trimolecular reaction between carbon monoxide and oxygen the ignition temperature is increased according to the equation $T=T'+80\ n'$ where

$$n'=\frac{\text{volume of the nitrogen } (N_2)}{\text{volume of the carbon monoxide } (CO)}.$$

The temperature coefficient of the reaction velocities for an increase of 10° is 1.31 between the limits 514° and 550° for a mixture of hydrogen and oxygen; and 1.24 between the limits 601° and 645° for a mixture of carbon monoxide and oxygen. The introduction of an indifferent gas (nitrogen) reduces the magnitude of this coefficient in proportion to the quantity added.

For a mixture of two volumes of carbon monoxide and one volume of oxygen Helier[19] gives the following maximum formation of carbon dioxide, expresed in per cent at the given temperature:

Degrees centigrade.	Per cent CO_2	Degrees centigrade.	Per cent CO_2
195	0.13	504	7.3
302	0.44	506	11.43
365	1.41	575	17.27
408	3.03	600	21.14
418	3.41	689	43.36
468	4.64	788	60.3
500	6.2	855	65.0

The formation of carbon dioxide from the carbon compounds in coal or even by burning carbon monoxide itself is no simple one. The dissociation of carbon dioxide into carbon monoxide and oxygen and the part that water plays in the reaction must all be considered. A perfectly dry mixture of carbon monoxide and oxygen can neither be exploded by means of a red glowing platinum spiral nor an induction spark.[20] The particles of water themselves play an important part in the reaction. Even at ordinary temperatures there is a small amount of free hydrogen and free oxygen in water vapor. The equilibrium at 10° contains one volume of free hydrogen and one-half volume of free oxygen for every $4.55 \cdot 10^{53}$ volumes of water vapor. The higher the temperature the greater the amount of uncombined gases in proportion to water vapor. When the equilibrium is reached at 100° there is one volume of free hydrogen and one-half volume of free oxygen for each $1.14 \cdot 10^{17}$ volumes of undissociated water vapor.[21] At very high temperatures free hydrogen and oxygen are present in such quantities that they may be directly determined. These free gases are chemically very much more active than the water molecules themselves. The

[19] *Ann. de Chim.* (1897) (7), 10, 521; *Chem. Centrbl.* (1897) I, 68, 487.
[20] Dixon, *Chem. News* (1882), 46, 151.
[21] Bodländer: *Ahren's Samm. chem. u. chem. tech. Vorträge* (1899), 3, 388.

oxygen unites readily with carbon monoxide to form carbon dioxide or the hydrogen with oxygen to form water or hydrogen peroxide. If the dissociation equilibrium is disturbed in either of these ways, more water molecules dissociate into hydrogen and oxygen atoms. When a temperature of the furnace is reached where this dissociation takes place faster than the dissociation of the oxygen molecules of the air, we have an explanation of the catalytic action of water in the combustion of coal and why a high combustion chamber temperature is desirable.

In the combustion of a highly bituminuous coal, the extent of the loss due to the carbon monoxide and hydrocarbon gases of the gasified coal passing up the stack before combustion is complete may be seen by an examination of the following table:

Element.	Product of combustion.	Heat of combustion in calories.[22]
Carbon	Carbon monoxide	2,435
Do	Carbon dioxide	8,140
Hydrogen	Water	34,180

It will be observed that each unit of carbon burned only to carbon monoxide will result in a loss of 5,715 calories (over half) and each unit of hydrogen unburned will result in a loss of 34,180 calories. In these experiments this loss has been regulated as well as possible with the dampers and air supply at my disposition, but a difference in construction of the boiler plant would seem advisable for some of the varieties of coal. Approximately perfect combustion can be obtained by proper boiler and furnace design, construction and operation.

An extremely rapid rate of evaporation, a low chimney temperature and completeness of combustion are incompatible. Messrs. Breckenridge, Parr and Dirks[23] found that the maximum rate of evaporation was obtained with the boiler running at its rated capacity, with the flue-gas temperature at about 260° C. With an increase in the rate of combustion the flue-gas temperature increased and the evaporation dropped off. Most of the Philippine coals easily gave a rate of evaporation equal to that obtained with Australian coal on an ordinary run.

Absorption.—Highly bituminous coals are likely to cause a deposit of soot which reduces the efficiency of the heating surface. Boilers must be thoroughly cleaned before beginning tests. The necessity for this precaution is evident in that if the drum and tubes are insulated from the hot gases on the one side by a layer of soot and from the water on the other by a layer of scale, the absorption will be imperfect and the greater this insulation the more resistance to absorption and the greater

[22] Calculated from the numbers of J. Thomsen: Thermo-chemische Untersuchungen (1882), 2, 52, 283 and 288.

[23] *Univ. of Ill. Bull.* (1906), 3, 39.

the loss to the stack by the gases escaping at too high a temperature as compared with that of the steam in the boiler.

Breckenridge *et al*[24] from results of boiler trials made to determine the effect of soot deposits on the evaporation in a horizontal tubular boiler conclude that it is not very marked. They found that the soot burned upon reaching a certain thickness, leaving but a very thin layer. Even with frequent and perfect sweeping of the tubes, no boiler cools the furnace gases to the temperature of the steam, but a certain amount of this heat waste may be recovered and the efficiency somewhat raised by the use of an economizer in the stack.

The effect of scale on the transmission of heat through boiler tubes is very variable, the mechanical structure of the scale being at least as important a factor as the mere thickness. Schmidt and Snodgrass[25] have investigated this effect on locomotive boiler tubes and feel warranted in summing up the results of their tests in the following conclusions:

"1. Considering scale of ordinary thickness, say of thicknesses varying up to one-eighth inch, the loss in heat transmission due to scale may vary in individual cases from insignificant amounts to as much as 10 or 12 per cent.

"2. The loss increases somewhat with the thickness of the scale.

"3. The mechanical structure of the scale is of as much or more importance than the thickness in producing this loss.

"4. Chemical composition, except in so far as it affects the structure of the scale, has no direct influence on its heat transmitting qualities."

Boiler pressure.—The true boiler efficiency is the ratio of the heat absorbed to the heat which is available to the boiler; that is, that portion of the heat in the furnace gases which is above the temperature of the steam. From this it is evident that the higher the working pressure—that is, the higher the steam temperature—the less difference between a fixed temperature of the furnace gas and that of the steam and therefore the less heat available to the boiler. In order to obviate this difference in efficiency I have tried to maintain approximately the same steam pressure in the various tests. In those cases where there is a deviation, the efficiency attained is greater or less than the average accordingly as the steam temperature is greater or less. The facts have not been established giving the exact value of the effect for all changes in steam pressure upon the evaporative efficiency of a boiler. Goss[26] has shown that "changes in steam pressure between the limits 120 pounds and 240 pounds will produce an effect upon the efficiency of the boiler which will be less than 0.5 pounds of water per pound of coal." The difference is not large for the small ranges of pressure common in stationary practice; and although slightly more heat is available and

[24] *Loc. cit*

[25] *Univ. of Ill. Bull.* (1907), 4, No. 15, 1.

[26] High steam pressure in locomotive service (1907), 10. Published by the Carnegie Institute of Washington.

absorbed when a low steam pressure is used, there is a limit below which one can not go, for new losses appear which more than compensate the gain.

Radiation.—A portion of the heat value is lost by radiation through the fire doors and furnace walls. By the use of a larger furnace and boiler the exothermic loss would be less. More favorable figures than mine have been attained by the Manila Electric Light and Railroad Company for Australian coal of the same source and similar composition as that of tests Nos. 1 and 2, Table II; however, it must be remembered that they operate their steam boilers in large units and that my figures are thoroughly representative of plants of 75-horsepower rating.

Other factors.—There are many other factors which enter into consideration such as the physicial condition of the coal,[27] small experimental errors in its use, personal variables, air leaks which dilute and cool the gases before absorption takes place, relative load carried, moisture from the air and the water of combustion which must be expelled through the stack as superheated steam, etc. Perhaps the greatest of these variables are the fireman and the moisture of the air.

As a rule, the fireman is a cheap laborer secured more for his muscle than his brains, is indifferent to his work and does it in the way that requires the least energy and initiative on his part. A fireman must be intelligent or have constant intelligent supervision to obtain good results. In hand firing, instead of carefully spreading the coal or coking it and then working it back gradually, a stoker will often spread over the fire a tremendous amount of green coal. In this way the flames are smothered, the instantaneous evolution of combustible gases is out of all proportion to the supply of air, they are cooled perhaps below their ignition temperature and thus a large quantity leaves the system unburned. A deep fuel bed is called for in a producer-gas plant, but in steam boiler practice where a complete combustion is desired so that all of the carbon of the fuel will be converted into carbon dioxide a thin fuel bed is needed. When it is noticed that the steam pressure does not respond to the new supply of coal, the fireman with a slice bar or hoe will stir up the new fuel together with that already on the grate, the result being still further loss of coal. Greatly increased evaporation and saving of coal will be obtained by prohibiting these practices. The tendency of most stokers is toward a too frequent use of the bar. If Philippine coal is properly stoked it is not necessary to poke the fire at all. I have made a test of seven hours on this coal without once putting a bar in the fire box.

The great difference in the moisture going into a furnace day by day, largely due to the variation of the daily humidity as well as that between the dry months and the rainy season, had often been noted; but it was left for Mr. Gayley[28] to obtain definite data and show the considerable

[27] There is a marked tendency of the coal from certain parts of the Philippines to fall to pieces. Care must be exercised to prevent the production of a large amount of slack in handling for it reduces the value for steaming purposes.

[28] *Iron and Steel Inst.* (1904), October.

economy in the working of blast furnaces by reducing the moisture in the air blast to a low and practically constant amount. It is stated as demonstrating this economy that prior to drying the air, throughout a period of eleven days the daily production of iron in the blast furnace was 358 tons with an average consumption of 2,147 pounds of coke per ton of iron, while for a period of sixteen days when the dry-air blast was used the daily production of iron was 417 tons with an average consumption of 1,726 pounds of coke per ton of iron. This shows a credit balance of 20 per cent greater output of iron and 20 per cent reduction in fuel consumed per unit of pig iron and output. However, there are other considerations. Unquestionably the greater output was largely caused by the more perfect maintenance of the regularity of the furnace owing to the practically constant amount of water in the blast. The gases in the former case were composed of 22.3 per cent of carbon monoxide and 13 per cent of carbon dioxide escaping at a temperature of 538° and in the latter of 19.9 per cent of carbon monoxide and 16 per cent of carbon dioxide escaping at a temperature of 376°, so that the economy of fuel is partly traceable to more perfect combustion and less loss through the escape of the gases. However, the fact remains that the saving through the use of dry air and the loss due to the specific heat of the moisture in the use of ordinary air is a great one, and this applies alike to all combustion furnaces.

The moisture of the air is a large factor in the tropics, where the atmosphere is of almost unvarying temperature, the thermometer normally standing at 30°, and the humidity is high, the air often being almost completely saturated. The average weight of the water entering the furnace in the above tests was about 5 per cent of the water evaporated in the boiler.

Even when all of these factors are taken into consideration there are sometimes abnormalities in the evaporative efficiency of a boiler which it is hard to explain. Some boilers owing to individual superiority, due to rapidity of water circulation, the use of water that does not foam, etc., are more efficient than others; some furnaces burn all of the volatile matter of a coal while others waste it and even the same furnace behaves differently with different coals.

Theoretically, the volatile matter should be expelled from a coal on the grate and the fixed carbon simultaneously burned, thereby keeping the fuel bed intensely hot. The combustion of the volatile combustible matter should be completed in the combustion chamber. Coals high in fixed carbon burn with a short, hot, smokeless flame and combustion is nearly completed a short distance above the fuel bed, but with highly volatile coals the combustion is incomplete even at the rear of the combustion chamber.

I have already shown[29] that when Philippine coal is rapidly heated in the ordinary laboratory analysis according to the directions recommended by the committee appointed by the American Chemical Society,[30] there is a very large mechanical loss amply indicated by the shower of incandescent carbon particles which are driven off during the first one or two minutes heating. Without the most careful stoking in the furnace there is probably the same rapid expulsion of the volatile matter as in the laboratory method, with a corresponding quantity of fine particles carried mechanically in the gas stream and to a greater or less extent deposited or burned out of the range of the absorption tubes. I have also shown[31] that the presence of water serves to dampen down and hold together the solid particles of a coal, thereby preventing mechanical loss. This is probably where the advantage, if any, comes when an engineer wets a highly volatile coal.

It has been shown[32] that fuels classified according to the increasing percentage of volatile combustible in their total combustible matter, when burned under a Heine boiler decrease somewhat in efficiency. While this conclusion holds when the number of samples averaged is sufficiently large, one must avoid too wide an application of the generalization. Often there are physical features and special reasons for choosing one coal before another when theoretically it is not so good. In coking and non-coking coals and in those entirely different physically, for example, slack and briquettes, clinkering and non-clinkering, there are factors which have many times more weight and such a generalization hardly could be applied to these, while such a comparison is perfectly legitimate and helpful to coals of the same class and physical condition.

It is hoped that as soon as the public realize the availability of reliable information regarding coal, both concerning its composition and steaming value, these means of determining its value may be more often resorted to and that guesswork may be eliminated from the purchase of a coal.

SUMMARY.

The object of this investigation was to determine the steam-making value of the coals of the Philippine Islands as compared with the foreign coals offered on the market in this Archipelago.

All the tests which are described in full were made at the Bureau of Science with a 75-horsepower water-tube Babcock & Wilcox steel boiler over a hand-fired furnace. An average of 111½ per cent of the rated capacity and an average steam pressure of 7.4 kilograms per square

[29] Cox, A. J.: *This Journal, Sec. A* (1907), **2**, 43.

[30] *J. Am. Chem. Soc.* (1899), **21**, 1116.

[31] Cox, A. J.: *Loc. cit.* 59.

[32] *U. S. G. S. Bull.* (1907), **325**, 89.

centimeter (105 pounds per square inch) was maintained. The average length of the tests was about seven hours. The plant, the apparatus used and all conditions were preserved as nearly constant as possible. It was my purpose to burn each coal with the maximum economy in this type of furnace. For a Philippine coal a regular and uniform method of firing is essential. It was found that the best method of firing was in small quantities every four or five minutes. A thin fuel bed is also needed and it must not be frequently worked. An entire test of seven hours duration was made without once disturbing the fire.

Inert matter in a coal is detrimental to its value in that the total number of heat units is proportionally decreased. Moisture further reduces the efficiency directly by the specific heat of the water, but the content of ash ordinarily found in Philippine coal has very little if any further effect. It seldom produces clinker and for this reason the presence of sulphur is no detriment. Moreover the percentage of sulphur in Philippine coal is usually extremely small.

A short fire box, the usual vertical baffling and an ordinary bar grate are not suited successfully to burn Philippine coal. An average of 9½ per cent less of the theoretical heat units were absorbed by the boiler when Philippine coal was consumed in the plant of this Bureau than with the Australian coal ordinarily used and for which the plant was selected and installed. The efficiencies recorded in Table II include those of the boiler, fire box and grate.

There is very little variation in the steam pressure and the amount of water evaporated per hour. When a boiler with a satisfactory rate of water circulation, absorbing surface, etc., has been used the deviation from the maximum efficiency of a plant depends largely on the adaptability of the furnace grate and stack. The economy is greatest with those coals which have a high fuel ratio, burn completely and give a high combustion chamber temperature. With satisfactory absorption the greater the difference between the temperature of the combustion chamber, gases and the boiler, the greater the efficiency and the less the loss to the stack. When Philippine coals are burned in an ordinary furnace they are at a disadvantage as they tend to burn out of the range of the boiler tubes with the result that there is low evaporation and high chimney temperature. A longer fire box or an increased number of baffle walls, or both, and a carefully selected grate would probably greatly increase the efficiency of Philippine coals. If the number of baffle walls is greatly increased, care must be exercised that there is sufficient draft.

The tendency to burn out of the range of the boiler tubes which coals high in volatile matter show, is aggravated by an excessive draft. The greater the quantity of air drawn through the fuel bed, the more rapid the combustion and the farther in the rear of the combustion chamber it takes place. With a heavy draft the result is high chimney temperature

and low efficiency. On the other hand, too little air results in low efficiency due to incomplete combustion.

Highly bituminous coals deposit much soot which may reduce the efficiency of the heating surface, and the formation of scale is a factor which needs close attention if maximum efficiency is to be attained. With a change in efficiency other factors of the heat distribution also vary. The radiation is especially variable with the size of the plant and the temperature of the combustion chamber.

The size of the fuel is a very important factor. The crumbling of coal reduces its value for steaming purposes. There is a tendency of coal from some parts of the Philippines to fall to pieces. Care must be exercised in handling to prevent this.

The moisture of the air is a large factor in the tropics. With an evenly warm, almost saturated; atmosphere the amount of water entering the furnace is enormous and considerably lowers the capacity and efficiency of the plant.

The average of the calorific values of all the Philippine coals tested is 6,003 [33] calories and that of the Australian coal [34] purchased by the Government and furnished to this Bureau for fuel is 6,614. In individual cases the calorific value of Philippine coal is as much as that of the Australian coal and in one case showed an efficiency in this plant, which is unfavorable to Philippine coal, within 3.75 per cent as great as that attained when the Australian coal was fired.

With respect to ash, clinker formation and the production of smoke the Philippine coals are superior to any others offered on the Manila market.

[33] 9/5 calories=B. T. U.

[34] This coal was tested in June, 1907 (tests Nos. 1 and 2, Table II).

ILLUSTRATIONS.

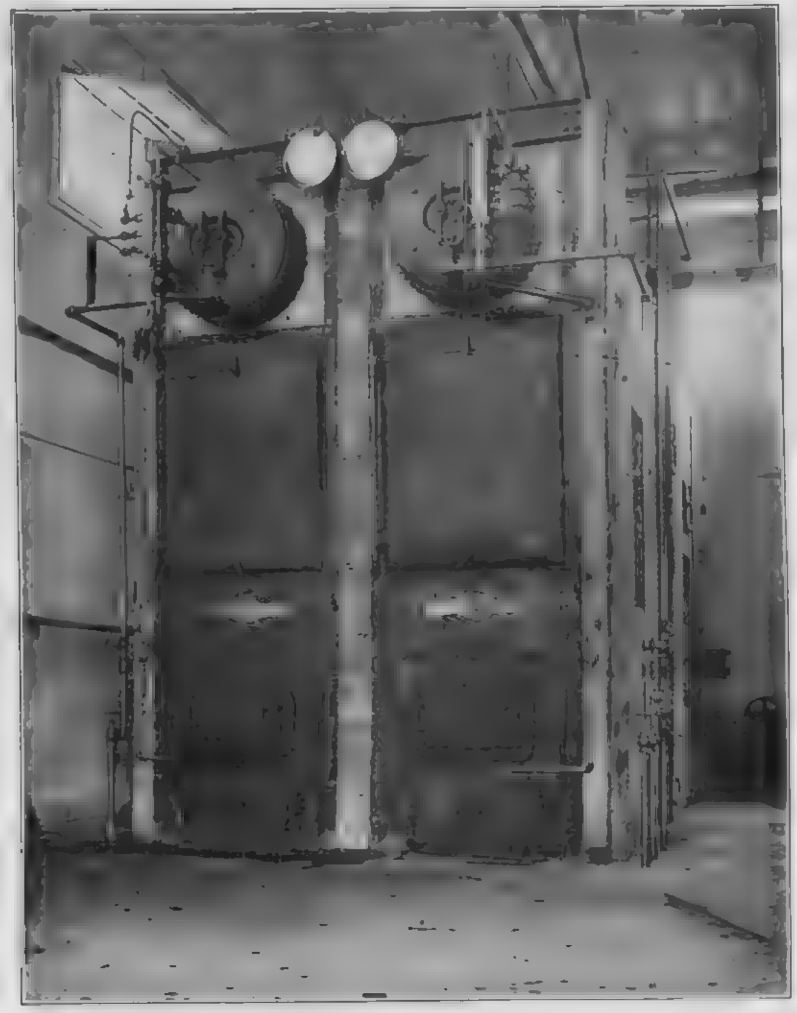
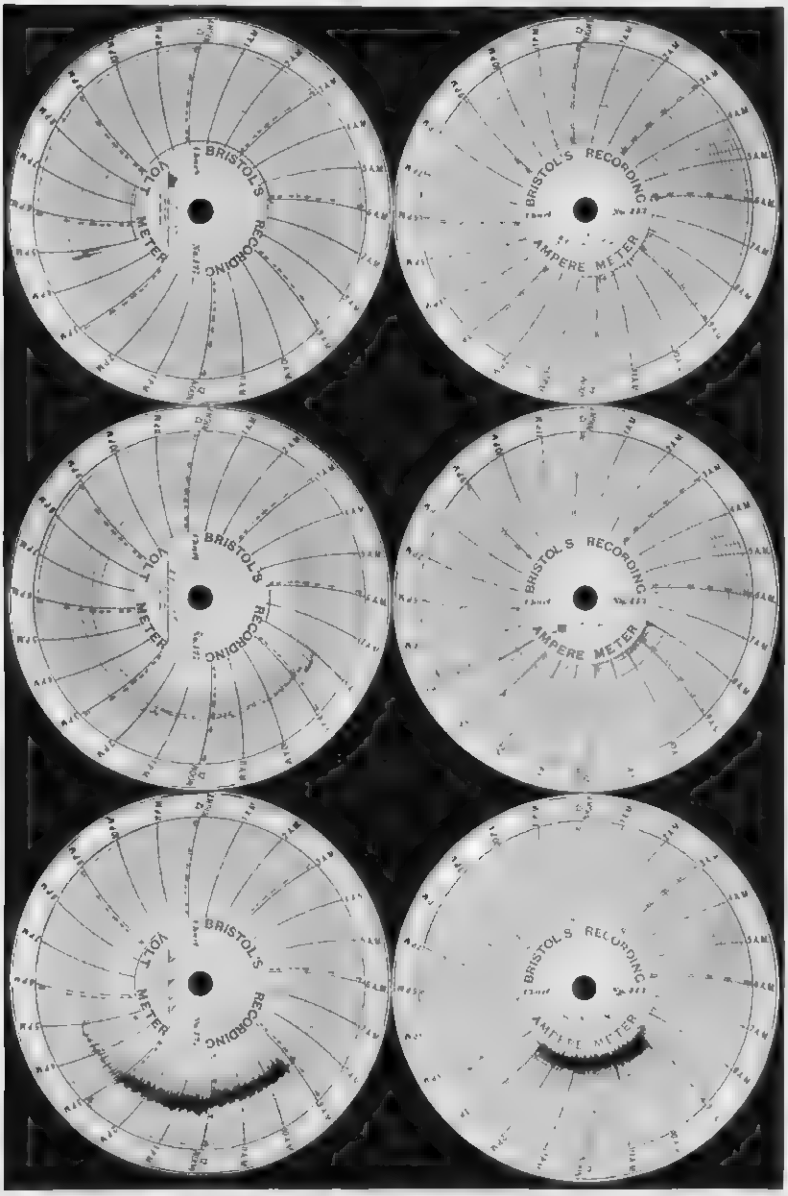


PLATE I.


BRISTOL'S RECORDING
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AMPERE METER
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VOLT METER
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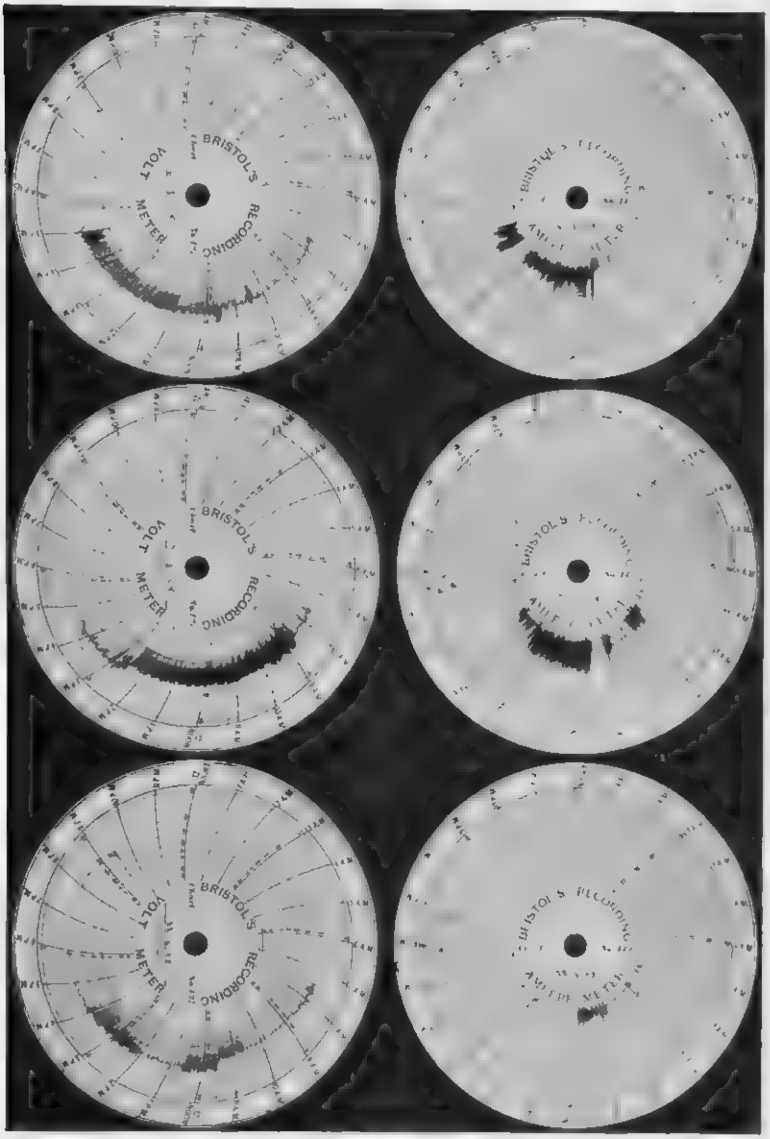
AMPERE METER

PLATE II.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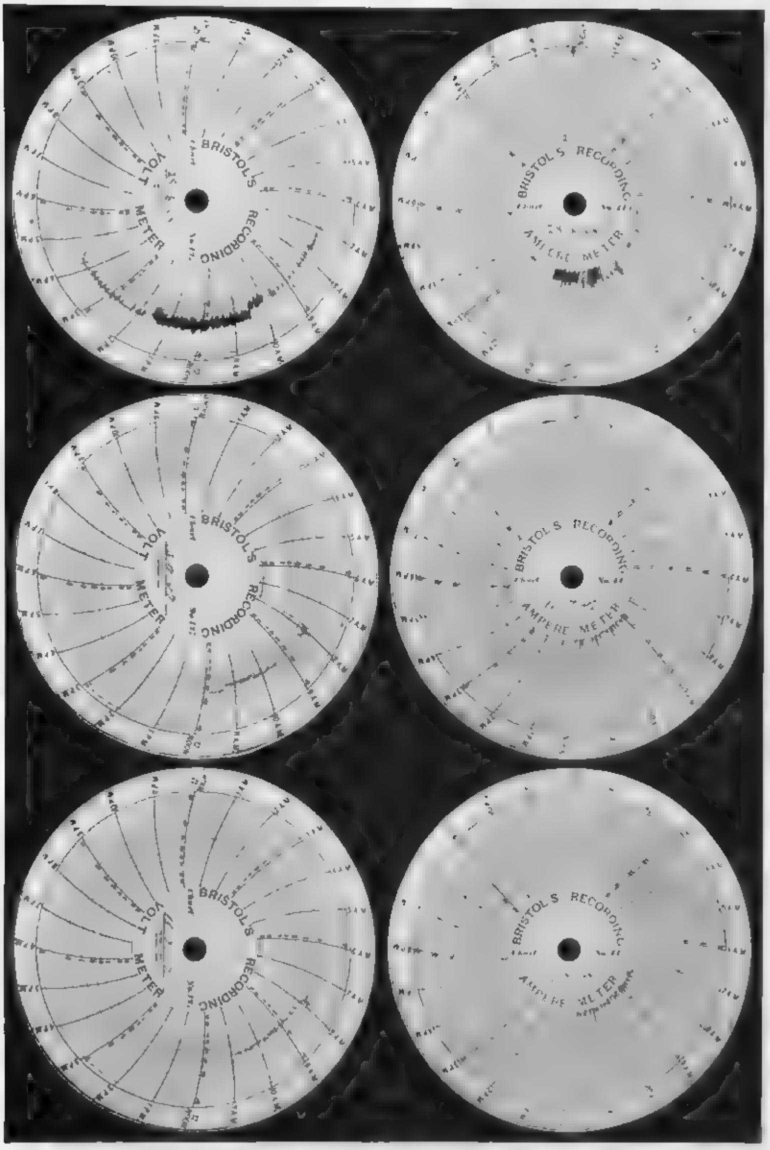
AMPERE METER

PLATE III.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BRISTOL'S RECORDING VOLT METER
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BRISTOL'S RECORDING VOLT METER
BRISTOL'S RECORDING AMPERE METER

PLATE IV.

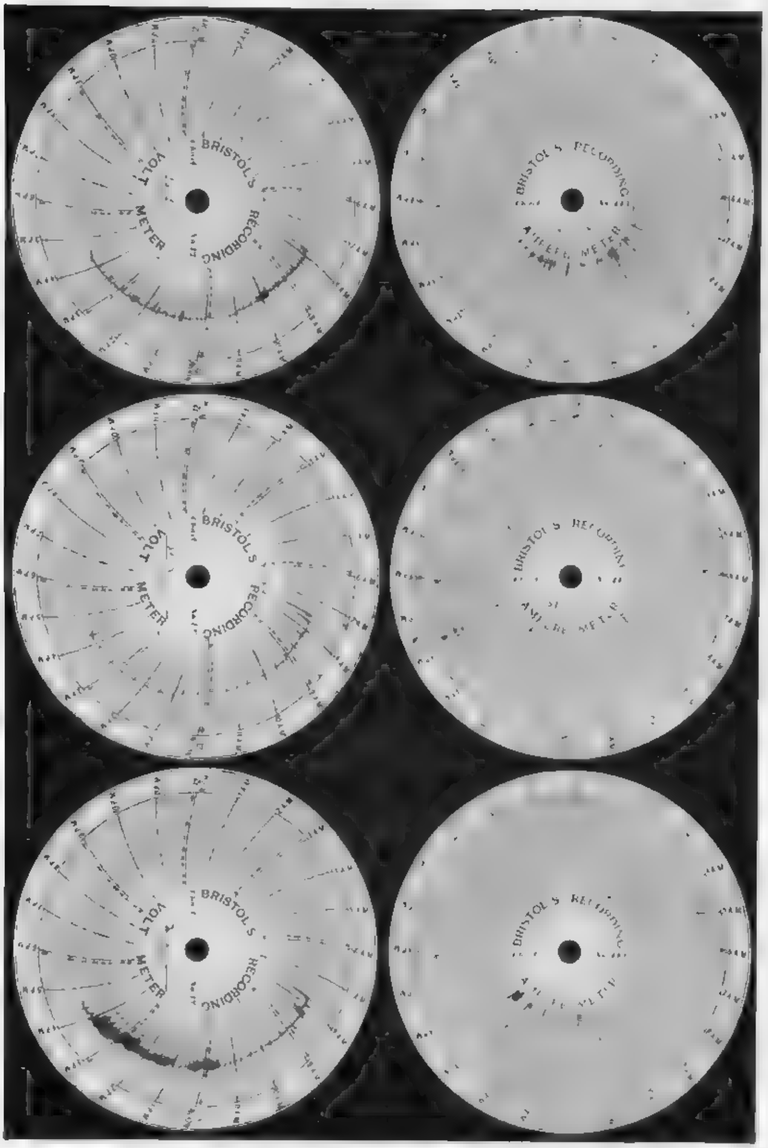
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PLATE V.

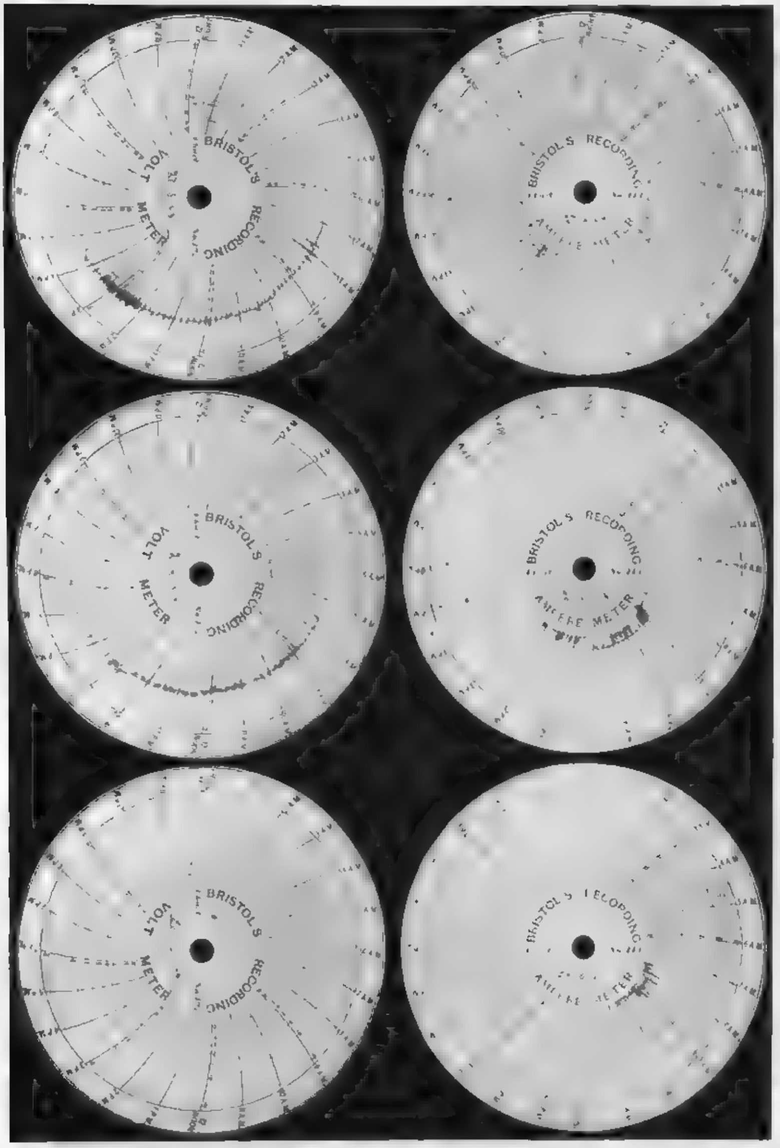
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PLATE VI.

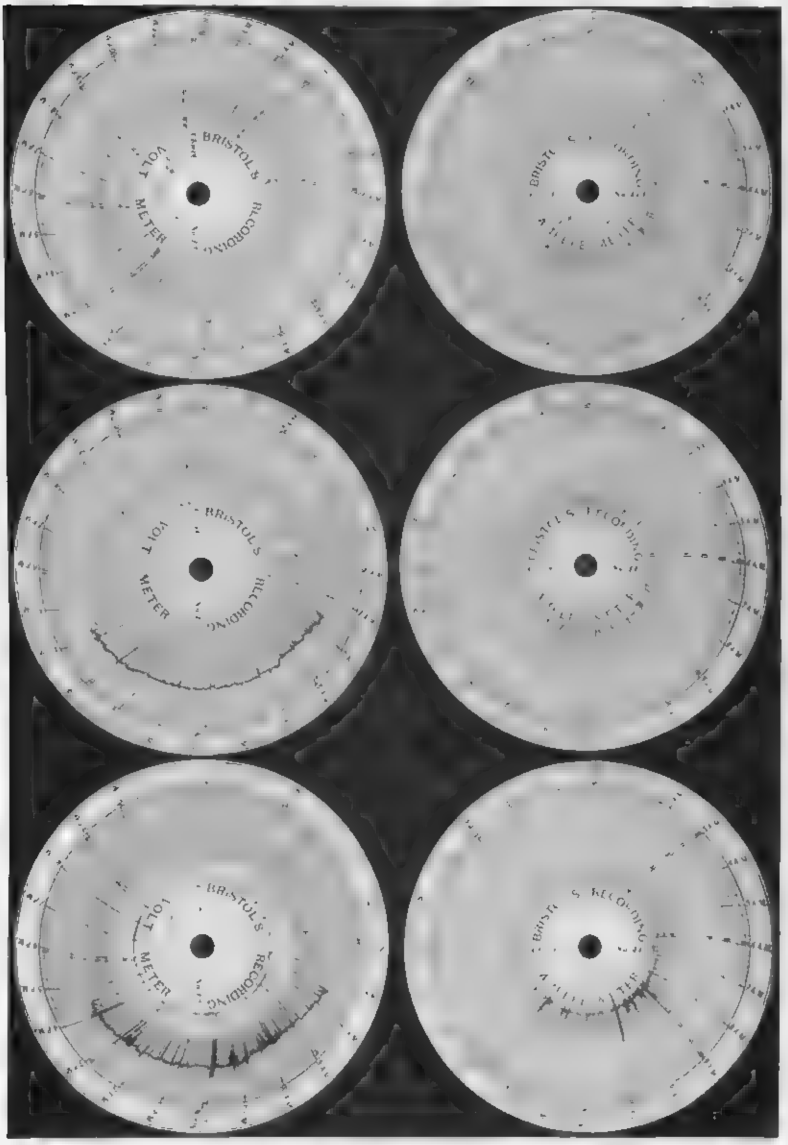


PLATE VII.

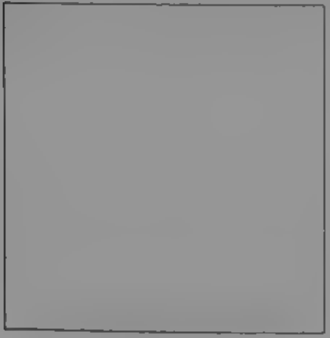


Fig. 1

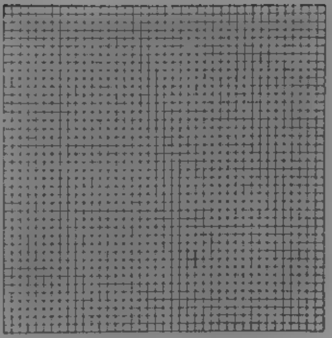


Fig. 2

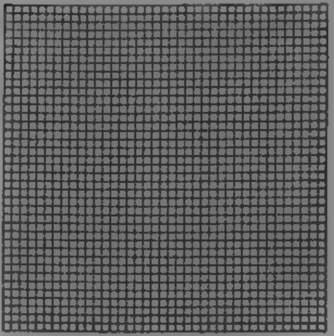


Fig. 3

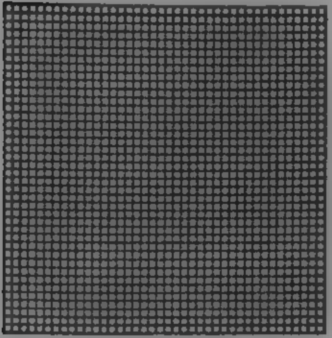


Fig. 4

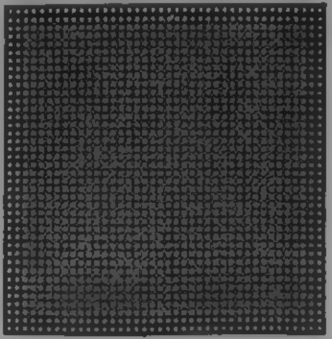


Fig. 5

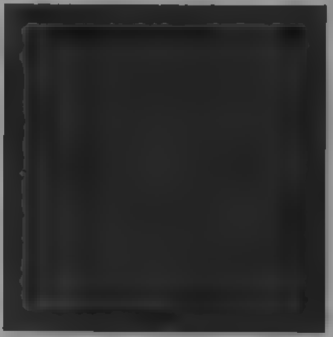
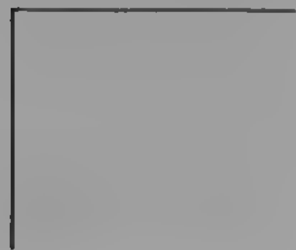
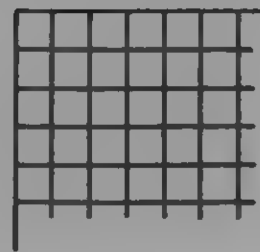


Fig. 6

PLATE VIII.



No. 1



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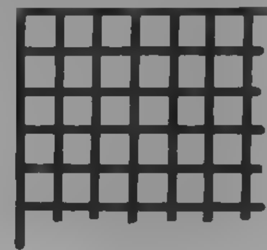

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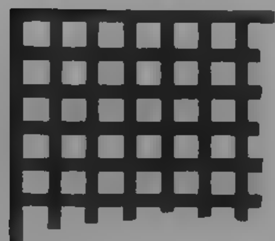

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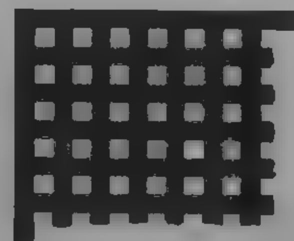

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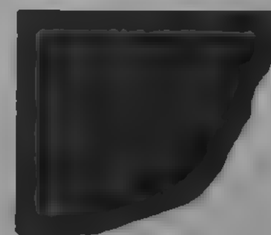


No 6

PLATE IX.

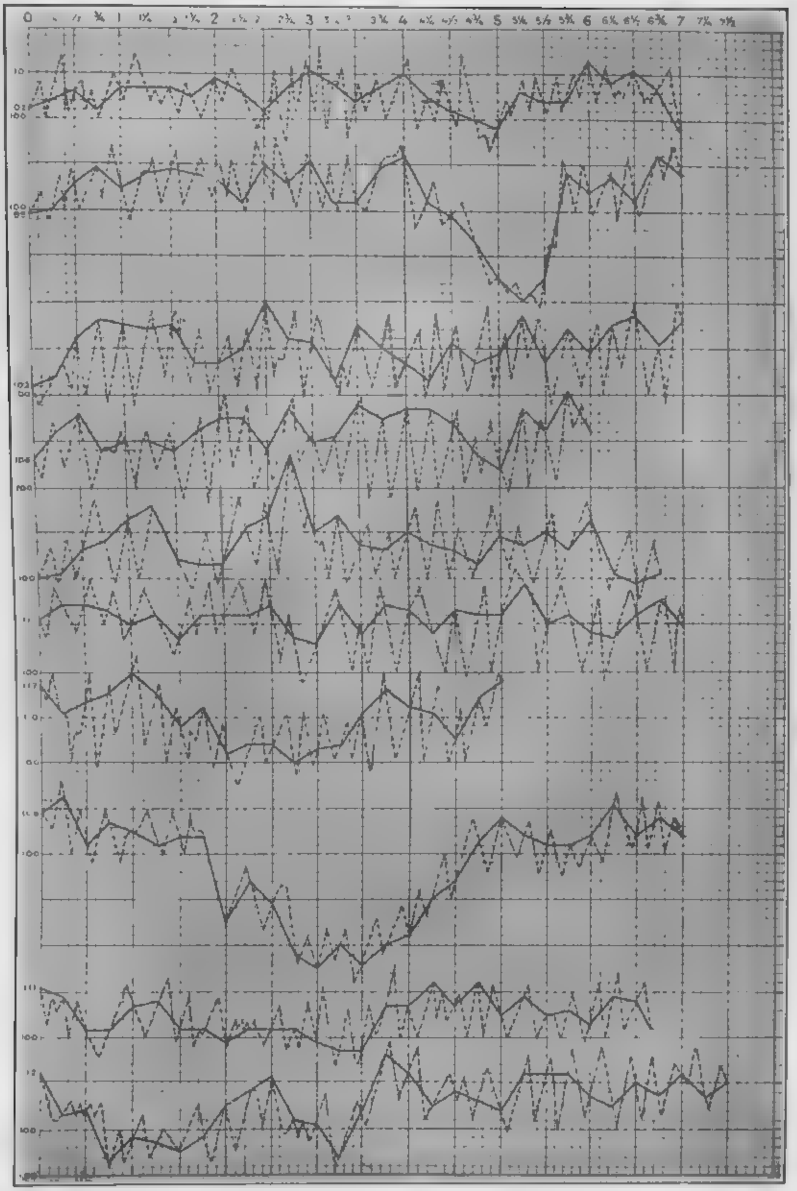


PLATE X.

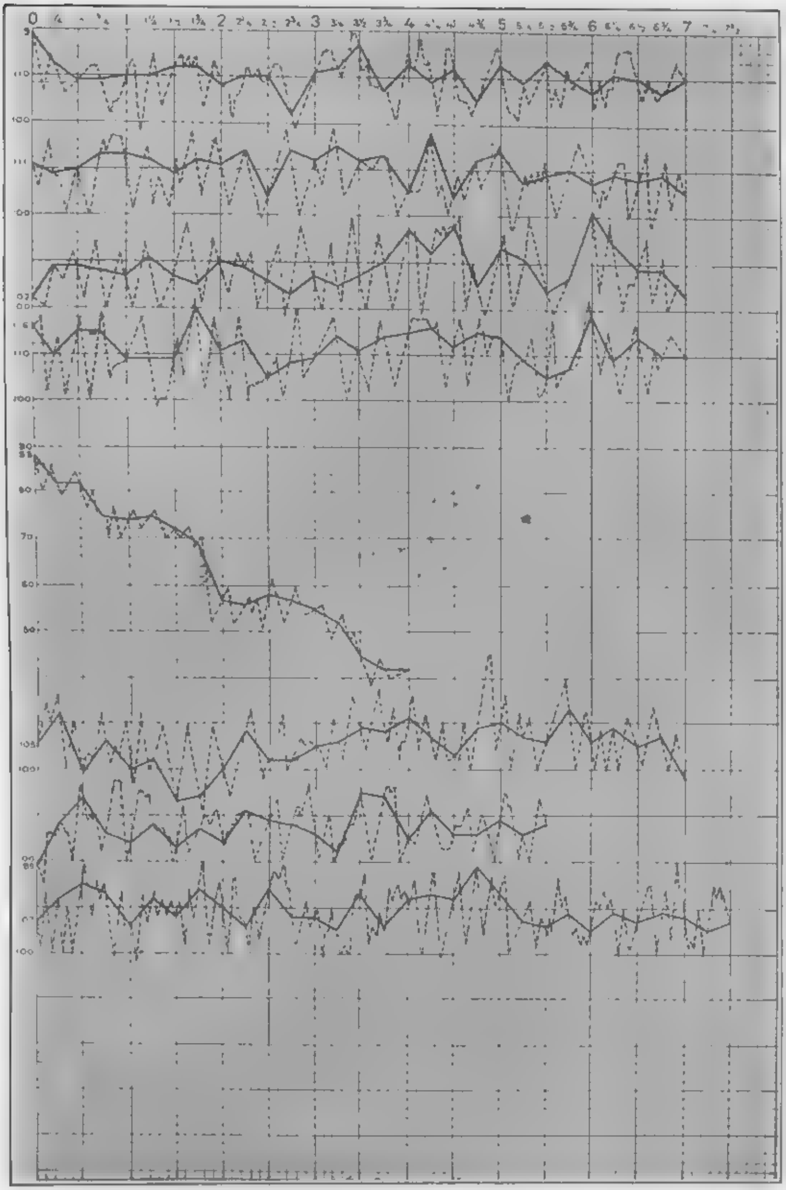


PLATE XI.

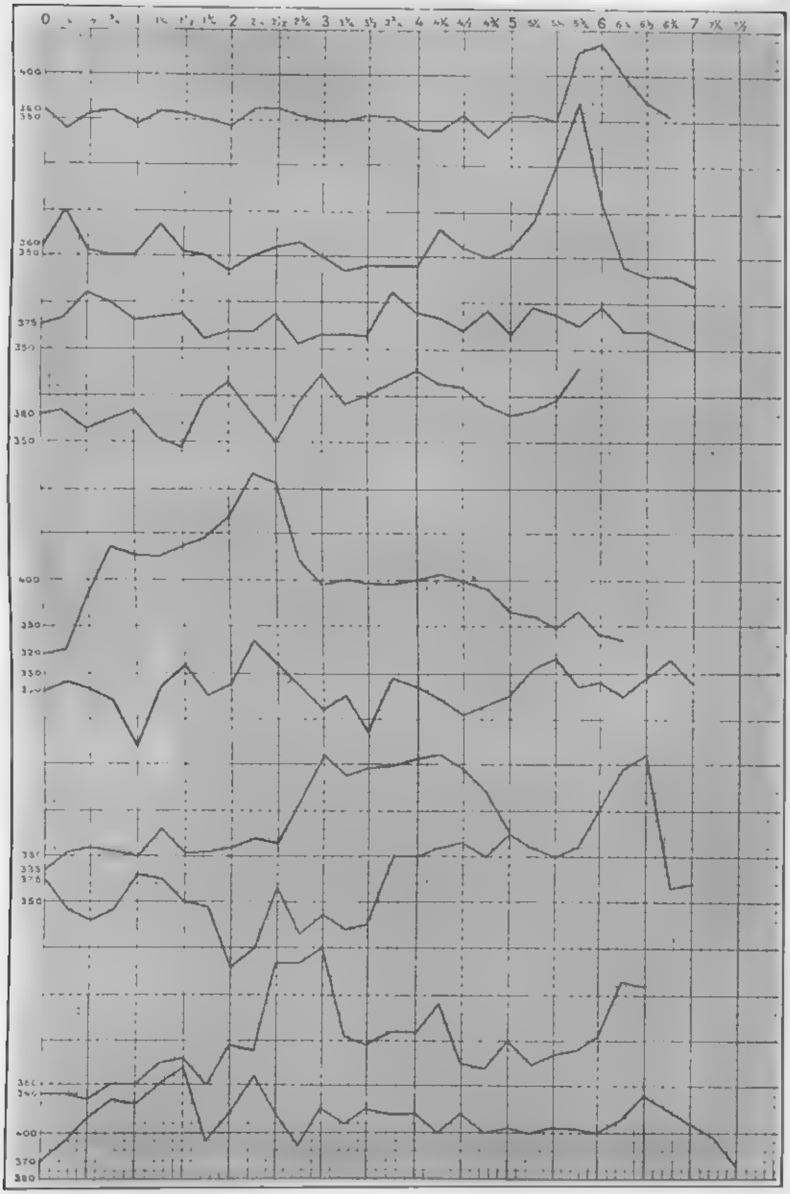


PLATE XII.

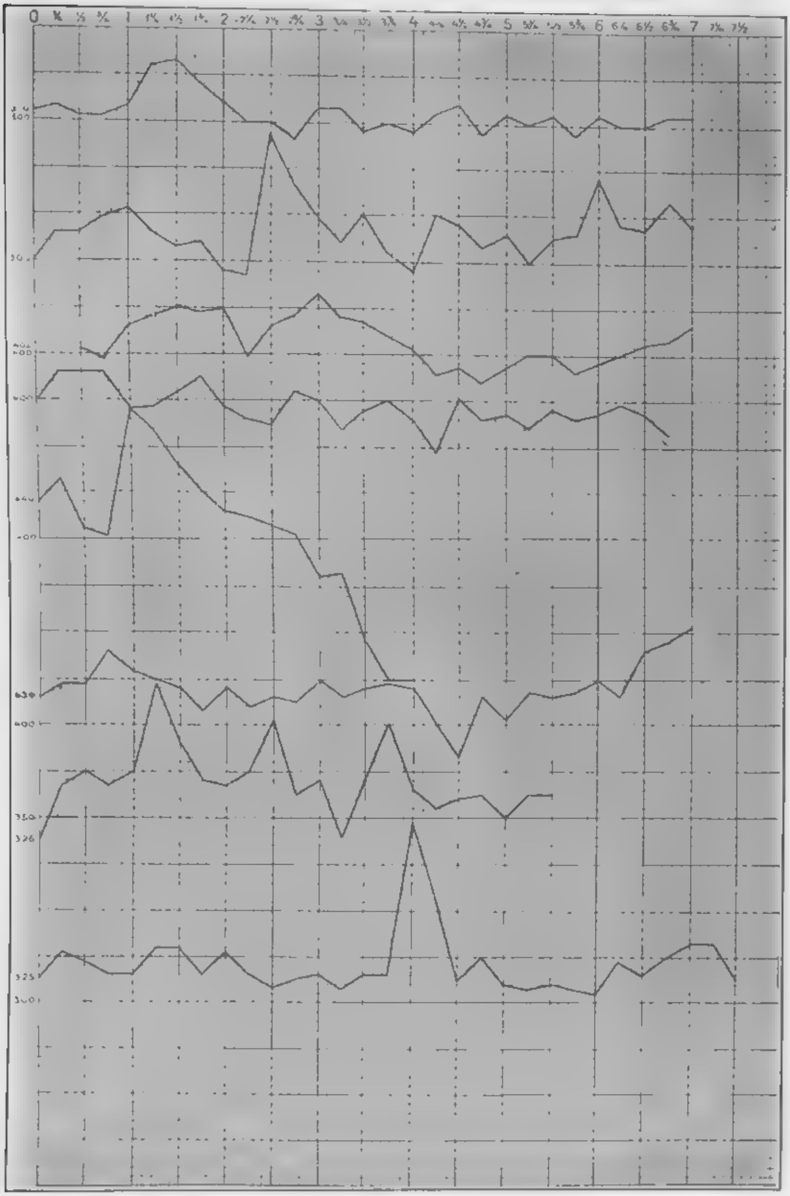


PLATE XIII.

METHYL SALICYLATE II.[1]—SOLUBILITY IN WATER AT 30°.

By H. D. Gibbs.

(*From the Laboratory for the Investigation of Foods and Drugs, Bureau of Science, Manila, P. I.*)

In the studies of the hydrolysis of methyl salicylate, the results of which will be published later, it became advisable to determine with some degree of accuracy, the solubility of the ester in water and in some other solutions in which the rate of hydrolysis was being measured.

No accurate measurements have been found in the literature. Cahours[2] records that the oil is scarcely soluble in water. The United States Pharmacopœia[3] and the National Standard Dispensatory[4] say that it is sparingly soluble and the Chemiker-Kalender[5] "wenig löslich;" statements evidently originating from the observations of Cahours made sixty-five years ago.

The method of analysis employed is essentially the same as that described in the first paper. The solution in which the methyl salicylate is to be determined is filtered to remove any undissolved ester (the first few drops passing through the filter being discarded), made strongly alkaline with sodium hydrogen carbonate to unite with and hold back any free salicylic acid, extracted repeatedly; not less than three times, with chloroform and the chloroform extracts run into about 20 cubic centimeters of a 10 per cent solution of sodium hydroxide and saponified in a steam bath. After evaporation of the chloroform the salicylic acid is extracted and made to a definite volume with water for the color comparisons.

When the comparison is made with standard solutions prepared with salicylic acid, the color shades are different, owing to the formation of small quantities of other phenolic compounds besides salicylic acid in the hydrolysis of the ester, and are quite difficult to match in the wedge colorimeter. Some eyes read the percentage very much too low, while

[1] The first article on the occurrence and determination of salicylic acid in methyl salicylate, the separation and determination of the two substances in foods and drugs, and the hydrolysis of the ester with sodium carbonate and sodium hydroxide appeared in *This Journal, Sec. A.* (1908), **3**, 101, and *J. Am. Chem. Soc.* (1908), **30**, 1465.

[2] *Ann. d. Chem. u. Pharm.* (1843), **48**, 61.

[3] 8th ed. (1900), 290.

[4] (1905), 970.

[5] (1907), **1**, 164.

others have the opposite tendency. Very satisfactory standards are prepared by dissolving a weighed quantity of pure methyl salicylate in chloroform and carrying through the saponification in the same manner as the determinations. Standards, representing from 1 to 2 milligrams of methyl salicylate in 50 cubic centimeters of solution, have been found to be most satisfactory for comparison with the wedge colorimeter.

The solutions for analysis were prepared by agitating a large excess of pure methyl salicylate in water varying in purity from that of the usual laboratory distilled product to a conductivity of 2.8×10^{-6} at 30°.[6] As the rate of hydrolysis of the ester in $\frac{N}{10}$ sulphuric acid is under investigation, the solubility in this strength of acid has been determined from time to time as the hydrolysis proceeds.

In the following tables, No. is the number of the determinations, T is the time expressed in hours during which the solutions were agitated, S is the quantity of substance used in the determination, expressed in cubic centimeters, and Q is the methyl salicylate found in solution and expressed as grams of solute in 100 cubic centimeters of solvent.

TABLE I.—*Solubility of methyl salicylate in water (temperature, 30°).*

No.	T	S	Q
1	18	5	0.063
2	66	10	.069
3	139	10	.076
4	854	10	.076
5	881	10	.071
6	978	5	.074
7	2,160	5	.093
8	336	5	.074

Determinations Nos. 1 to 6, inclusive, were made upon different portions of the same solution, prepared by constantly agitating in a bottle 10 cubic centimeters of methyl salicylate and 500 cubic centimeters distilled water at 30°±1°. No. 7 is the analysis of a mixture of 15 cubic centimeters of distilled water and 0.5 cubic centimeter of methyl salicylate which had been agitated in a sealed glass tube for three months, at temperatures varying from 30° to 100°. The system had approached an equilibrium and the amount of methyl salicylate hydrolized was found to be 0.0125 gram.[7] No. 8 is the analysis of a mixture of 10

[6] In standardizing cells at 30°, I have used the temperature coefficients found by Jones and West, *Am. Chem. Jour.* (1905), **34**, 381.

[7] This determination is not to be taken as an accurate measure of the equilibrium or the rate of hydrolysis for the reason that the action of the solutions on the glass was found to be considerable. A portion of the salicylic acid was found to be present in the form of the sodium salt.

cubic centimeters of water, conductivity 2.8×10^{-6} at 30°, and 0.6 cubic centimeter of methyl salicylate which was agitated in a sealed tube at 30°±1°. This determination is probably as reliable as any that have been made and represents a fairly accurate average. Electrodes were sealed into this cell and measurements of the conductivity of the aqueous phase showed that it had changed but little during the last seven days of the ten days' agitation.

TABLE II.—*Solubility of methyl salicylate in $\frac{N}{10}$ sulphuric acid solution (temperature, 30°).*

No.	T	S	Q
1	66	10	0.077
2	139	10	.077
3	354	10	.076
4	978	5	.078

It is to be expected that the solvents will show a constantly increasing capacity for dissolving the ester as the hydrolysis proceeds, owing to the slowly increasing concentration of the methyl alcohol, one of the products of the hydrolysis. The rate of the increase in the concentration of the ester is very slow as shown from the tube of distilled water which had been agitated for three months with the solute. The concentration of the methyl salicylate had increased to 0.093, and from the determination of the salicylic acid the concentration of the methyl alcohol in the aqueous solution was found to be approximately 0.02 gram per 100 cubic centimeters. Since the rate of hydrolysis in acid solutions is more rapid than in water, it is probable that the increase in the concentration of the ester will be more rapid in the former than in the latter.

SUMMARY.

The solubilities of methyl salicylate in pure water and in $\frac{N}{10}$ sulphuric acid solution at 30° have been determined. The average of a number of determinations is 0.074 gram per 100 cubic centimeters for the former solvent and 0.077 for the latter.

Slight improvements in the colorimetric method for determining methyl salicylate as given in the first paper are described.

THE COMPOUNDS WHICH CAUSE THE RED COLOR IN PHENOL.

By H. D. Gibbs.
(*From the Laboratory for the Investigation of Foods and Drugs, Bureau of Science, Manila, P. I.*)

Much investigation and speculation has been indulged in by various writers concerning the cause of the red coloration of phenol. At this time it is well established that impurities in phenol may produce a discoloration. It is also true that pure, colorless phenol is reddened by the action of moisture, air and the more refrangible light rays; in other words by hydrogen peroxide oxidation. The color has been considered to be due to various compounds, but I have found, after investigating the samples which have come under my observation in this laboratory, that the true nature of the colored compounds and the method of their formation is not to be found in the literature.

A brief review of the literature shows the most prevalent idea to be that the coloration is due to impurities. Some of the latest text-books on organic chemistry still cling to this theory.

H. Müller[1] states that phenol will keep well if the impurities are resinified by the action of the air on the alkaline solution during the process of purification.

H. Hager[2] attributes the formation of color to the action of the oxygen and ammonia of the atmosphere, which, in his opinion, probably produce rosalic acid.

A. Sicha[3] says the coloration is due to copper. He prepared phenol which remained colorless for months in the sunlight by distilling in glass vessels. W. Meyke[4] believed the color to be caused by the lead of the containing vessel. P. Ebell[5] states that phenol crystals contain substances which are colored through the action of light. These substances are not metals as is claimed by Meyke.

H. Hager[6] found some samples to be colored by the presence of iron, and he inclines to the view that the red color can not result from a chemical change of the phenol. The basis for the red color does not lie alone in the iron content and may be caused by the raw material or the method of purifying and washing.

[1] *Dingl. Poly. Journ.* (1866), **179**, 462.
[2] *Chem. Centrbl.* (1880), **11**, 178.
[3] *J. Soc. Chem. Ind.* (1882), **1**, 397.
[4] *Jahresb. f. Chem.* (1883), 875.
[5] *Ber. d. chem. Ges.* (1884), **17**, 69, Ref.
[6] *Chem. Centrbl.* (1885), **16**, 120.

Probably a corallin or tropæolin compound formed by the action of ammonia and ozone of the air prduces the color.

A. Kremel[7] believes that the red color is produced by a large number of metals and metallic oxides, particularly copper, and then lead, silver, and zinc. Tin has no action. He says that these metals enter into combinations, the result being that these compounds dissolve in phenol with a red color. This compound can not be rosolic acid for the reason that it dissolves in concentrated sulphuric acid with a blue color, whereas rosolic acid does so with a yellow color. E. Mylius[8] believes that the glass vessels exercise an influence by giving up alkali when they are easily acted upon by the phenol.

E. Fabini[9] states that the red color is due to the action of hydrogen peroxide in the presence of metallic salts and ammonia. He ascribes the formation of the color to the production of ammonium phenate which is converted into a phenate of the metal present, iron or copper, and which is in turn acted upon by hydrogen peroxide, yielding the red coloring substance which he calls phenerythrene. This compound is soluble in alcohol and phenol, coloring the latter red. It dissolves in sulphuric acid with a blue color.

A. Bidet[10] states that phenol which is carefully purified will remain colorless on exposure to air and light. W. Hanko[11] finds that the coloration is due principally to oxidation. The presence of thiophen, creosol or parakresol does not affect the color. Metals such as copper, iron, and lead and their salts, as well as ammonia and ammonium chloride, accelerate its formation. J. Boes[12] believes it to be highly probable that an isophenol described by Brunner[13] is the cause of the red coloration. Cumaronon is not the cause.

Kohn and Fryer[14] have found that the coloration requires the presence of moisture, air, and light rays, or in the absence of light rays, hydrogen peroxide, and that the presence of metallic impurities accelerates the color formation. They conclude that the colored compound is an oxidation product of phenol and can be formed in pure phenol under the proper conditions of light, moisture, and oxygen. No coloration occurs when the phenol is protected by ruby glass.

A. Richardson[15] has proved the presence of hydrogen peroxide in phenol which has been exposed to the light and he concurs in the opinions of Kohn and Fryer. The light waves at the blue end of the spectrum are the ones which produce the effect and not those at the red.

Kohn[16] repeats that the coloration will take place in pure phenol, when moisture and oxygen are present, under the action of the more refrangible light rays. A. Bach[17] says that while phenol reddens by the action of air, moisture and light

[7] *J. Soc. Chem. Ind.* (1886), **5**, 160.

[8] *Chem. Centrbl.* (1887), **18**, 251.

[9] *J. Soc. Chem. Ind.* (1891), **10**, 453.

[10] *Bull. Soc. Chim.* Paris (1891), III, **5**, 13. *Compt. rend. Acad. d. sc.* Par. (1889), **108**, 521.

[11] *Ber. d. chem. Ges.* (1892), **25**, 386, Ref.

[12] *Chem. Centrbl.* (1902), II, **73**, 50.

[13] *J. pr. Chem.* (1902), **173**, n. s. 65, 304.

[14] *J. Soc. Chem. Ind.* (1893), **12**, 107.

[15] *Ibid*, 415.

[16] *Chem. News* (1893), **68**, 163.

[17] *Chem. Centrbl.* (1894), II, **65**, 318.

the reaction is not as simple as Kohn and Fryer or Richardson believe it to be. He excluded air by working in an atmosphere of carbon dioxide and found that under these conditions the coloration was still produced in the sunlight. He could demonstrate no traces of hydrogen peroxide in the mixture.

J. Walter[18] finds that the presence of iron salts increases the production of the red color. He attributes the coloration to the action of hydrogen peroxide.

L. Reuter[19] has observed that by adding sulphur dioxide to phenol it can be kept colorless for an almost unlimited period. Since the discoloration of phenol does not interfere with its application in medicine he recommends that, to avoid accidents, all phenol be uniformly, artificially colored rather than treated with preserving or decolorizing agents.

EXPERIMENTAL.

The samples of phenol investigated were the purest crystallized products which could be obtained from various manufacturers. In this climate, where the sun's actinic rays are so very intense, they assume a brilliant red color very quickly; it is in fact difficult to preserve the white crystals after a bottle has been opened. Exceptional opportunities are here offered for the study of reactions which are at least in part due to the catalytic action of light rays. The prevailing temperature is 30° and the variations are within rather narrow limits. Many of the reagent bottles standing upon the shelves in a well-lighted laboratory give a distinct reaction for hydrogen peroxide, and whenever tests for hydrogen peroxide are to be made the reagents employed must be purified and tested. Under these conditions appreciable amounts of the reaction products under investigation are produced in the minimum of time.

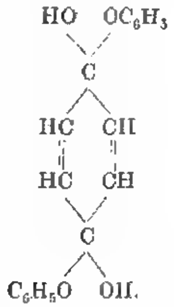
I have found that quinone, or a quinone derivative is the principal colored compound formed, although during the oxidation of phenol to quinone it is to be expected that other substances will be produced.

Cross, Bevan, and Heiberg,[20] on oxidizing benzol with hydrogen peroxide, found the products to be phenol, catechol, quinol, and quinone. Martinon[21] demonstrated that phenol when oxidized with hydrogen peroxide produced catechol, quinone, and quinol. It is to be expected that the oxidation of phenol will produce the ortho and para derivatives and no meta compounds.[22]

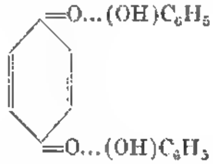
Quinone dissolves in phenol, producing a brilliant red solution. A very small crystal dropped into liquid, colorless phenol reddens immediately upon striking the phenol and is slowly dissolved, producing the characteristic red solution.

[18] *J. Soc. Chem. Ind.* (1899), **18**, 360.
[19] *Ibid* (1905), **24**, 686.
[20] *Ber. d. chem. Ges.* (1900), **33**, 2017.
[21] *Bull. Soc. Chim.* Paris (1885), **43**, 155.
[22] Thiele, *Ann. Chem.* (*Liebig*) (1899), **306**, 129.

Quinone and phenol condense readily forming phenoquinone to which Jackson and Oenslager[23] have assigned the formula:



Willstätter and Piccard[24] offer the criticism of this formula that it does not explain the color of the compound or its instability. They suggest the graphic representation:



in which the dotted lines are partial valences. This compound is very unstable. The dilute, aqueous, alcoholic and ligroin solutions are almost colorless and in all probability the condensation product is decomposed on solution in these solvents. On evaporating the solvents the red color gradually makes its appearance as the concentration increases. The aqueous solution reacts in such a way as to show the presence of quinone.

Methods for separating small quantities of quinone from large quantities of phenol have all proved unsatisfactory. In some cases the condensation product, phenoquinone, if not already present will be produced, while in others quinone will be obtained by the breaking down of phenoquinone, if the latter is present. The presence or absence of phenoquinone in the solvent phenol can probably only be proved by physico-chemical methods which have not been adopted in this work.

Samples of colorless phenol to which a few drops of water were added were placed in the sunlight in clear, glass bottles, the liquid half filling the bottle. The samples reddened in a few hours and after four days were so brilliant in color that an analysis was attempted. Other samples which had reddened upon the laboratory shelves upon long standing, were analyzed at the same time.

On pouring small quantities of the red phenol into ten or twenty times the volume of water, an almost colorless solution is formed. The samples which had reddened upon long standing upon the laboratory

[23] *Ber. d. chem. Ges.* (1895), 28, 1614. *Am. Chem. Jour.* (1896), 18, 1.
[24] *Ber. d. chem. Ges.* (1908), 41, 1464.

shelves separated a small quantity of an insoluble, red compound, while those which had been in the sunlight for four days formed a clear solution with no insoluble portion. The red precipitate was collected upon a filter. It was insoluble in water, very slightly so in ligroin and quite soluble in alcohol, forming a red solution. The compound, with the exception of the differences in the solubilities noted, behaves in the same manner as phenoquinone. With alkalies it turns to a blue-green and with concentrated sulphuric acid it forms a brilliant blue-green color. The coloring qualities of the substance are intense. A small amount dissolved in phenol or alcohol produces a brilliant red solution. It is possible that this compound is the ortho modification of phenoquinone. The amounts obtained were so small that no analysis was made.

Reactions for catechol were obtained from the clear solutions, which were almost colorless with a slightly yellow tinge. On addition of lead acetate a copious, white precipitate was formed. After treating this precipitate with sulphurous acid and filtering, catechol was extracted with ether from the filtrate. On evaportion of the ether in a vacuum desiccator, crystals which were proved to be catechol by the ferric chloride and sodium hydrogen carbonate reaction, separated.

On treating 20 cubic centimeters of the phenol which had reddened in the sunlight with a small quantity of sulphurous acid and distilling in steam until all of the phenol had passed over, the residue in the distilling flask was found to contain a very small amount of red precipitate similar to that obtained from the old samples of phenol upon pouring into water. This was collected upon a filter and was found to react with solvents, sodium hydroxide, and concentrated sulphuric acid in the same manner as the red compound separated from other samples. The filtrate, upon extraction with ether, demonstrated that considerable quantities of catechol and quinol were also present.

Quinone was demonstrated by the hydrocoerulignon reaction of Liebermann.[25] The coerulignon employed in this test was made by the method of Hofmann,[26] except that methyl sulphate was substituted for methyl iodide in the production of the dimethyl ether of pyrogallol. It is to be noted that in the presence of considerable quantities of phenol the coerulignon precipitate has a reddish tinge and it does not under these conditions change readily to the steel-blue color which is characteristic of these crystals. Since pure, white crystals of phenol in concentrated, aqueous solution fail to give any coloration whatever, while the red phenol immediately gives a distinct cloudiness which soon becomes red and extends downward throughout the solution, it is fairly safe to assume that the reaction is positive. When the red phenol is

[25] *Ibid* (1877), 10, 1615.
[26] *Ibid.* (1878), 11, 336.

dissolved in a very small quantity of water containing just enough potassium hydroxide so that the resulting solution is almost neutral, a copious precipitate of the steel-blue crystals of coerulignon is obtained on adding a drop of the hydrocoerulignon reagent. If the solution becomes too alkaline through the addition of too much caustic alkali it can be made acid with acetic acid before the addition of the Liebermann reagent. An aqueous solution of phenoquinone will also give this reaction for quinone, the coerulignon crystals being very characteristic. This is to be expected from the fact that phenoquinone is a compound of very slight stability.[27]

Hydrogen peroxide has been found to react with hydrocoerulignon, producing the characteristic coerulignon crystals. The samples of red phenol which were found to react with the hydrocoerulignon reagent were tested for hydrogen peroxide and while traces were indicated by both the vanadic acid and the titanic acid reactions, the amounts seem to be too small to account for so great an oxidation of hydrocoerulignon. Any considerable amount of hydrogen peroxide would hardly be expected to be present if it reacts with the phenol to produce oxidation products.

One cubic centimeter of red phenol dissolved in about 15 cubic centimeters of water will liberate iodine from the potassium iodide reagent (potassium iodide dissolved in water with or without the addition of a little ferrous sulphate) as shown by the addition of starch solution. The blue color does not appear at once for the reason that the phenol reacts with the first portions of iodine set free. After some minutes, however, the blue starch compound is unmistakably present.

Another method which is in some respects more satisfactory for producing the reaction, is the addition of 1 cubic centimeter of the red phenol through a pipette reaching to the bottom of a test tube containing the solution of potassium iodide and starch, with or without a trace of ferrous sulphate. Immediately above the red layer will appear the starch-iodine blue. On gently rotating the test tube the blue starch compound will float upward through the colorless reagent. Colorless crystals of phenol will not produce this reaction. While quinone will set iodine free from a solution of potassium iodide its presence is not conclusively proved by this test for the reason that the hydrogen peroxide which may be present will produce the same reaction.

If the theory that the red color is caused by a phenol solution, or condensation of the oxidation products of phenol, principally quinone, is correct, phenol in dilute solutions under the same conditions of moisture, oxygen, and light rays should be oxidized and the solutions should be colored only by these oxidation products. Mixtures of the

[27] Jackson and Oenslager, *loc. cit.*

following proportions were sealed in tubes and agitated in the sunlight at about 30° for seven days.

1. Phenol 1 drop, chloroform 1 cubic centimeter and water 5 cubic centimeters.

2. Phenol 1 drop, chloroform 1 cubic centimeter and $\frac{N}{10}$ sulphuric acid 5 cubic centimeters.

3. Phenol 1 drop, chloroform 1 cubic centimeter and $\frac{N}{10}$ sodium carbonate 5 cubic centimeters.

In each case the tube was half filled with liquid, the remaining space being occupied by air. After a few hours in the sun the chloroform layers in each tube showed a yellow coloration. The aqueous layers in numbers 1 and 2 were colorless, while that in number 3 was slightly yellow. The colors continued to deepen and at the end of one week, when the tubes were opened, the chloroform was a deep yellow and in numbers 1 and 2 contained all the color, while in number 3 the yellow was equally distributed between the two solvents. Quinone was found to be present in every tube. The remaining portions were too small to work with separately; however, a composite mixture of the residues was found to contain catechol. It was to be expected in the tube number 3 that the aqueous layer would also be colored for the reason that quinone in alkaline solutions unites with oxygen to form more complex colored compounds, some of which are soluble in water.

A mixture of 5 grams of phenol, 100 cubic centimeters of chloroform, and 200 cubic centimeters of purified water, which had an electrical conductivity of 3.7×10^{-6}, was agitated in a liter bottle for eight days at a temperature of $30° \pm 1°$. The chloroform became yellow in one day and after eight days was a yellow-brown. On treating portions of the chloroform solution with sulphurous acid and distilling in steam until the phenol was volatilized, the residual solution was found to contain small quantities of quinol and catechol. The aqueous portion of the reaction mixtures shows considerable quantities of hydrogen peroxide by the titanic and vanadic acid tests and by the potassium dichromate and aniline reaction of Bach.[28]

In view of Bach's criticism of the statements of Kohn and Fryer (that the coloration of phenol requires oxygen, moisture and light rays), the experiments of Bach, in which he excluded oxygen by working in an atmosphere of carbon dioxide, were repeated and further extended by the employment of two other gases, hydrogen and nitrogen.

The experiments were carried on in sealed tubes and the necessary precautions were taken to exclude all substances except those the presence of which was desired. The hydrogen employed was generated in a steady, rapid stream by the action of

[28] *Compt. rend. Acad. d. sc.*, Par. (1894), 119, 1218.

sulphuric acid on pure zinc in a Kipp apparatus. From the generator it was passed through a solution of pyrogallol in caustic potash, concentrated sulphuric acid, tubes of soda lime and calcium chloride, a combustion tube of copper turnings and copper gauze heated to redness and finally a wash bottle of pure, concentrated sulphuric acid, from which it was led directly into the tubes in which the experiments were to be conducted.

The nitrogen was obtained by passing atmospheric air through five large wash bottles, each holding several liters of alkaline pyrogallol and then through the same train of apparatus used in purifying the hydrogen. Other indifferent gases of the atmosphere were, of course, present. The carbon dioxide was generated in a Kipp apparatus by the action of hydrochloric acid on marble. It was purified by passing through a calcium chloride tower and a wash bottle of pure concentrated sulphuric acid.

The phenol used was a pure sample beautifully crystallized. The crystals were removed from the bottle by means of platinum tipped forceps and transferred directly to the glass tube through which a rapid current of gas was passing. The form of tube employed and the method of sealing in the required gas so as to exclude all atmospheric air was that employed by Franklin[20] in his work with ammonia with the exceptions that no stopcocks were used on the tubes and at atmospheric temperature the interior of the sealed tubes were at atmospheric pressure.

The following ten tubes and no others comprise this investigation:

I. Phenol (about 2 grams), freshly boiled water 3 drops, sealed in a hydrogen atmosphere.

II. Phenol (about 2 grams), freshly boiled water 1 cubic centimeter, heated to boiling in a hydrogen atmosphere and then sealed.

III. Same as I, except sealed in nitrogen.

IV. Same as II, except sealed in nitrogen.

V. Same as I, except sealed in carbon dioxide.

VI. Same as II, except sealed in carbon dioxide.

VII. Phenol (about 2 grams), water 3 cubic centimeters, boiled in a carbon dioxide atmosphere and sealed.

VIII. Phenol (about 3 grams), boiled in a carbon dioxide atmosphere and sealed.

IX. Same as I, except sealed in atmospheric air.

X. Same as II, except sealed in atmospheric air.

These tubes were then placed in the direct sunlight and constantly agitated by means of a mechanical device.

Tubes IX and X showed a distinct color in a short time and were a light red color in two hours. The color, as nearly as can be judged by the eye, deepened constantly for about ten days. These two tubes are the only ones which show any color visible to the eye. At this writing they have been exposed to the sunlight for fifty-seven days. This work confirms that of Kohn and Fryer.

Since phenol and moisture sealed in this way in an atmosphere of an indifferent gas will form a delicate test for the presence of oxygen, tubes V, VI, and VII produce evidence that carbon dioxide and water

[20] *J. Am. Chem. Soc.* (1905), 27, 831.

do not react with each other in the presence of sunlight to form oxygen or hydrogen peroxide and other products according to the von Baeyer assimilation hypothesis. Bach,[30] however, states that he has produced this decomposition in the presence of uranium acetate by passing the gas into a solution of the salt in the sunlight, obtaining formaldehyde and hydrogen peroxide as the products. Euhler[31] severely questions these results. The decomposition of carbon dioxide in the presence of water has been effected by Löb[32] by means of the silent electric discharge, the products being carbon monoxide, oxygen, hydrogen peroxide, formic acid, and formaldehyde. It would thus appear that the reaction between carbon dioxide and water requires the presence of a more powerful catalytic agent than sunlight. From the work of Kastle[33] and others, it is evident that the presence of phenol, a peroxidase accelerator, would have a beneficial effect upon such a reaction when once it is started.

CRITICISMS OF SOME OF THE EARLIER WORK.

While it may be possible that some of the impurities in phenol such as ammonia, thiophene, creosol, parakresol, etc., may cause a discoloration as stated by Müller, Sicha, Meyke, Ebell, Hager, Kremel, Mylius, Fabini, and Bidet; impurities, other than moisture and oxygen, do not cause the coloration of pure phenol. The oxygen of the atmosphere was thought by Hager and Ebell to produce the red color through its effect upon the impurities present and not upon the phenol itself. Fabini, while he ascribes the action to hydrogen peroxide, also considers that impurities such as metallic salts and ammonia must be present.

Although Kohn and Fryer, and later Richardson, proved the cause of the coloration to be hydrogen peroxide, the explanation of the mechanism of the reactions involved is not entered into by them, except that the former hint at the possibility of an indophenol being present. The experimental proof upon which Bach bases his criticism of the work of Kohn and Fryer must be inaccurate. When he attempted to exclude oxygen by working in an atmosphere of carbon dioxide it is highly probable that he did not rigidly accomplish the desired result, or else other impurities were present.

Because Bach failed to find hydrogen peroxide in the mixture of phenol, water, and carbon dioxide it can not be considered proved that available oxygen was not present to react with the phenol. It is very improbable that rosolic acid, corallin, or tropæolin as suggested by Hager have produced the color in the samples of phenol investigated by him.

[30] *Ber. d. chem. Ges.* (1894), 27, 340.

[31] *Ibid.* (1904), 37, 3414. Bach's answer, *Ibid* (1904), 37, 3985; (1906), 39, 1672.

[32] *Ztschr. f. elek. Chem.* (1906), 12, 282.

[33] *Am. chem. Jour.* (1908), 40, 251.

The phenerythrene of Fabini may well be phenoquinone or a derivative of quinone. The existence of the isophenol of Brunner, to which Boes ascribes the color, is problematical.

Since quinone, produced by the oxidation of phenol, has been found to produce the major portion of the color in the samples examined by me, it is evident that sulphur dioxide as suggested by Reuter, and stannous salts as mentioned by Kremel will retard the production of the colored compounds, while many other metallic salts, as stated by Sieha, Meyke, Hager, Kremel, Mylius, Fabini, Kohn and Fryer, and Walter will accelerate this phenomenon by reason of their tendency to increase the rate of oxidation.

SUMMARY.

The tendency which phenol has to assume a red color on standing has generally been attributed to impurities. While several workers have proved that pure phenol is colored in the presence of moisture, oxygen, and light rays or by hydrogen peroxide oxidation, no explanations of the reactions involved have been made. This work has proved the principal products to be quinone and catechol. The major portion of the color in red phenol is produced by quinone or quinone derivatives in solution. The presence of the brilliant red condensation product, phenoquinone, is highly probable.

ON THE DETECTION AND DETERMINATION OF COCONUT OIL.[1]

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Hodgson[2] describes what purports to be an accurate method for the detection and estimation of coconut oil when used as an adulterant of butter. He states that he has found "the quantity of oxygen required to oxidize a given quantity of the saponified fat, is, in the case of butter fat, invariable."[3] In the case of coconut oil he finds the quantity of oxygen required to vary considerably in the twenty samples[4] examined, but the largest amount required by any of the samples is much less than that used by an equal amount of butter fat.[5] Hodgson maintains that the composition of mixtures of coconut oil and butter fat has been accurately determined[6] from this constant.

The method employed consists in the oxidation of 20 cubic centimeters of a 0.1 per cent aqueous solution of the saponified fat with $\frac{N}{10}$ potassium permanganate solution. The oxidation is carried on at the temperature of 100° in the presence of a large excess of sulphuric acid and potassium permanganate. The proportions are 20 cubic centimeters of a 0.1 per cent solution of the products of saponification, 50 cubic centimeters of $\frac{N}{10}$ potassium permanganate and 50 cubic centimeters of a 50 per cent solution of sulphuric acid. This mixture is heated for thirty minutes at a temperature of 100° and the excess of potassium permanganate titrated with $\frac{N}{10}$ oxalic acid or ferrous ammonium sulphate. Results of remarkable uniformity were obtained with various mixtures of butter and coconut oil.

[1] Since the completion of this paper a number of investigators have found Hodgson's method to be valueless. For the reason that no one has pointed out the real cause for its failure we are perhaps justified in publishing our results, even though we are again proving the fallacy of the method. We have been for some time experimenting upon coconut oil and our investigations in other directions than those chronicled here are being continued.

[2] *Chem. News* (1907), **96**, 273, 288, and 297.

[3] *Ibid*, 273.

[4] Obtained in Birmingham, England.

[5] *Ibid.*, 288.

[6] *Ibid*, 297.

In the hands of the writers this method has not only failed as a quantitative method for the estimation of coconut oil, but it has also failed to show any marked differences, which can be depended upon, between a number of different fats. The reason is easily found.

The permanganic acid which is formed upon acidification of a potassium permanganate solution is readily decomposed on exposure to light or on gentle heating, with the separation of oxides of manganese and loss of oxygen. On boiling the evolution of oxygen is more rapid.[7] Even a weak solution of permanganic acid continually evolves oxygen. Dammer[8] states that in the presence of an excess of sulphuric acid permanganic acid is reduced.

Morse, Hopkins, and Walker[9] have found that permanganic acid and potassium permanganate are reduced by precipitated superoxide of manganese with the liberation of three-fifths of the active oxygen and that solutions of potassium permanganate are more stable if freed from suspended oxide and kept in darkness or diffused light. Even pure solutions are decomposed in direct sunlight. Morse and Reese[10] state that they have "always found dilute, moderately acidified solutions of permanganate quite stable at ordinary temperatures, provided they were free from oxide," and that the decomposition of permanganic acid by the peroxide, attended by the liberation of oxygen, is a continuous reaction, which ceases only when all of the acid has been reduced to the oxide.

These references seem to have escaped the attention of Mr. Hodgson. He mentions no precautions which were taken to purify his permanganate solutions, does not speak of any decomposition of the permanganate and altogether has no difficulty in obtaining results, which in view of our knowledge of the behavior of permanganate solutions, are without sufficient experimental foundation.

Ross and Race[11] have found Hodgson's method to be "unworkable." Their experiments have shown them that "sulphuric acid of the strength prescribed exerts under the conditions laid down a considerable action on potassium permanganate" and that "owing to the retention of the hydrated oxides of manganese by the insoluble fatty acids liberated on the addition of acid" difficulty was experienced in obtaining a good end point. Thompson and Tankard[12] have found that the permanganate solution is attacked by the reagents used and pronounce the process "fundamentally unscientific and based upon error."

When the method of oxidation of the saponified fats is carried out according to the described method, the loss of active oxygen of the permanganate solution varies little in the case of each of the fats and oils with which we have experimented and moreover this loss in active oxygen is about the same as when distilled water is used instead of the soap solutions. In one case the lost oxygen escapes into the atmosphere,

[7] Roscoe and Schorlemmer: Treatise on Chemistry (1900), 2, 919.
[8] Handbuch der anorganischen Chemie (1893), 3, 251.
[9] *Am. Chem. Jour.* (1896), 18, 401.
[10] *Am. Chem. Jour.* (1898), 20, 526.
[11] *Chem. News* (1908), 97, 110.
[12] *Chem. News* (1908), 97, 146.

in the other it has some action upon the oxidizable organic matter present. The results recorded in the following table were obtained under uniform conditions and with permanganate solutions which were especially purified. All suspended oxides were removed by drawing the solution through a tightly packed asbestos filter 10 centimeters thick. A layer of oxides of manganese was visible on the top of the asbestos and at no point was the visible penetration greater than 1 millimeter.

TABLE I.—*Oxidation of fats with potassium permanganate solution.*

Laboratory No.	Samples.	Cc. of $\frac{N}{10}$ permanganate used.	Oxygen[13] equivalent.	Laboratory No.	Samples.	Cc. of $\frac{N}{10}$ permanganate used.	Oxygen[13] equivalent.
55157	Butter	38.5	164.0	49019	Lard	37.6	150.4
55157	do	38.5	164.0	14	do	37.8	149.6
23	do	37.7	150.8	14	do	36.5	146.0
23	do	37.6	150.4	14	do	37.3	149.2
22	do	38.4	158.6	2	do	39.7	158.8
22	do	38.4	153.6	2	do	39.8	159.2
25	Cacao butter	37.7	150.8	2	do	38.9	155.6
25	do	37.7	150.8	2	do	38.9	155.6
16	Coconut oil (rancid)	40.3	161.2	4	Olive oil	36.2	144.8
16	do	40.3	161.2	4	do	37.6	150.4
16	do	40.3	161.2	3	do	37.7	150.8
56109	Coconut oil (refined)	40.1	160.4	3	do	37.5	150.0
56109	do	40.1	160.4	3	do	37.5	160.0
32	Coconut oil	38.3	153.2	3	do	37.5	150.0
32	do	38.3	153.2	31	Linseed oil	37.2	148.8
33	do	39.3	157.2	31	do	37.2	148.8
33	do	39.3	157.2	28	Pili-nut oil	37.3	149.2
34	do	38.9	155.6	28	do	37.3	149.2
34	do	38.9	155.6	17	Oleic acid	35.5	142.0
6	do	40.6	162.4	17	do	35.5	142.0
6	do	40.5	162.0	18	Palmitic acid	39.6	158.4
27	Castor oil	36.3	145.2	18	do	39.6	158.4
27	do	36.3	145.2	19	Stearic acid	36.2	144.8
20	Imitation butter	39.0	156.0	19	do	36.2	144.8
20	do	39.1	156.4	29	Glycerol	36.2	144.8
58280	Lard	42.2	168.6	29	do	36.2	144.8
58280	do	42.2	168.8		Distilled water	38.3	153.2
49019	do	37.6	150.4		do.[14]	38.6	154.4

The various fats and oils require different amounts of oxygen for their complete oxidation to carbon dioxide and water. The glycerol esters of four of the most commonly occurring fatty acids and glycerol itself would have theoretically the following oxygen numbers.

[13] The so-called oxygen equivalent is the grams of oxygen times 100 required for 1 gram of fat.

[14] Different solutions of especially purified potassium permanganate were used to titrate some of the duplicates. Many other determinations, uniform with these and not recorded here, were made.

TABLE II.

Fat.	Oxygen equivalent.
Butyrin	196.7
Palmitin	287.8
Olein	289.6
Stearin	293.0
Glycerol	121.6

The oxidation as carried out by the previously described method does not go this far. If the 0.1 per cent solution of the products of the saponification are oxidized with $\frac{N}{10}$ potassium permanganate by the usual method of titration, the oxidation stops far short of complete production of carbon dioxide and water. A number of fats were treated by the following method:

To 25 cubic centimeters of the 0.1 per cent solution after saponification, were added 25 cubic centimeters of 50 per cent sulphuric acid solution. The mixture was kept at the boiling temperature and $\frac{N}{10}$ potassium permanganate added gradually, until the pink color remained permanent for three minutes. The evaporated water was replaced from time to time. An excess of permanganate was always indicated by a small quantity of suspended particles of the oxides of manganese.

Fairly concordant results were obtained. In the following table the averages of a number of determinations, and for comparison the iodine numbers, are given.

TABLE III.

No.	Sample.	Permanganate, cc. $\frac{N}{10}$	Oxygen equivalent.	Iodine[15] numbers (Hanus).
6	Refined coconut oil	7.8	24.96	8.-9.5
32	Coconut oil	7.5	24.00	
55157	Butter	12.4	39.68	26.-38
54452	do	11.7	37.44	
25	Cacao butter	12.8	40.96	32.-41
28	Pili-nut oil	15.0	48.00	59.8
13	Lard	15.6	49.92	62.6
2	do	15.4	49.28	67.4
27	Castor oil	21.8	69.76	83.-85
3	Olive oil	24.4	78.08	79.-88
31	Linseed oil	29.9	95.78	173.-180
29	Glycerol	28.0	89.6	

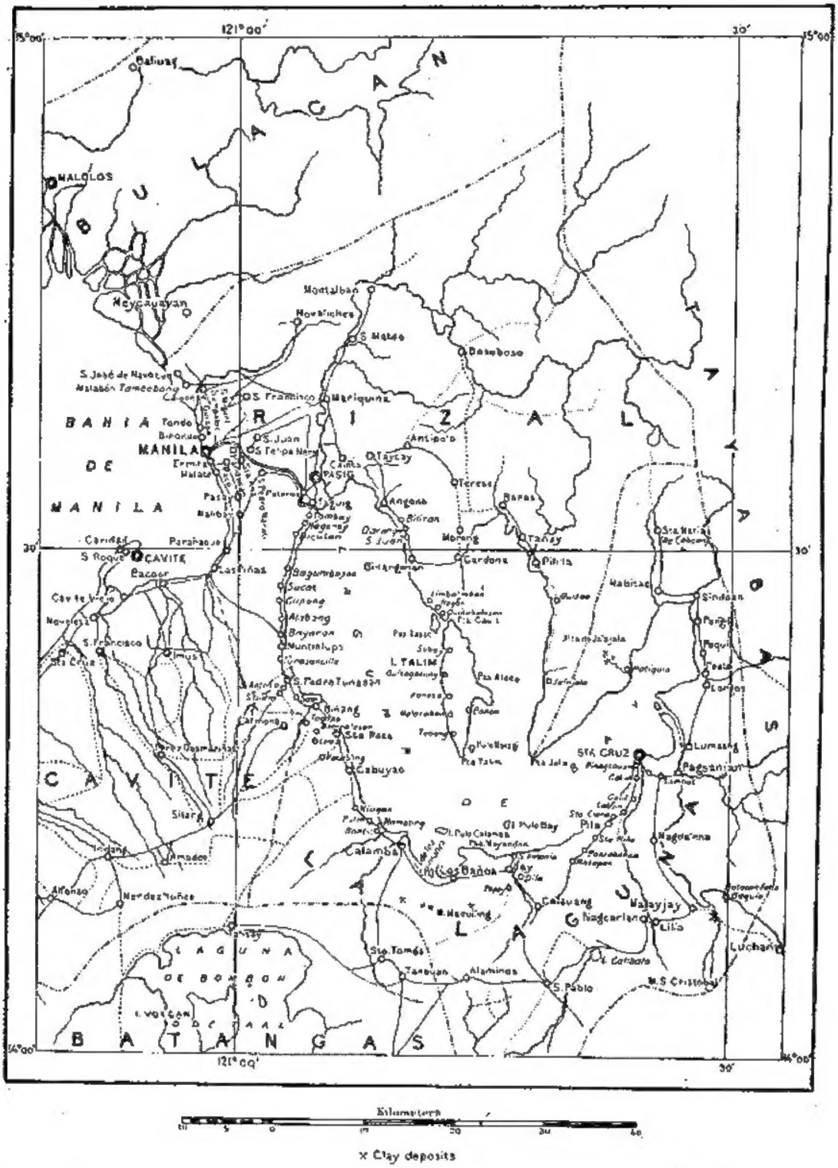
[15] The iodine numbers are taken from Lewkowitsch, "Oils, Fats, and Waxes," and from Leach, "Food Inspection and Analysis," except the pili-nut oil and the lards which are our own determinations.

It is readily seen that these results bear no relation to the amount of oxygen which would be required if the end products were carbon dioxide and water. They do, however, run parallel, in a measure, to the iodine numbers. We can see nothing to be gained by the employment of such a method. The determination of the iodine number is easier of manipulation, requires less time, and is more accurate. The work in other directions is being continued.

SUMMARY.

We have demonstrated both experimentally and from the known behavior of potassium permanganate that the method advanced by Hodgson for the determination of an "oxygen equivalent" for fats and oils has no theoretical or experimental foundation.

The products of saponification of the different fats and oils do require varying amounts of potassium permanganate for their oxidation. These amounts are, in a measure, parallel to the iodine numbers.



MAP OF LAGUNA DE BAY SHOWING THE REGIONS FROM WHICH THE CLAY WAS TAKEN.